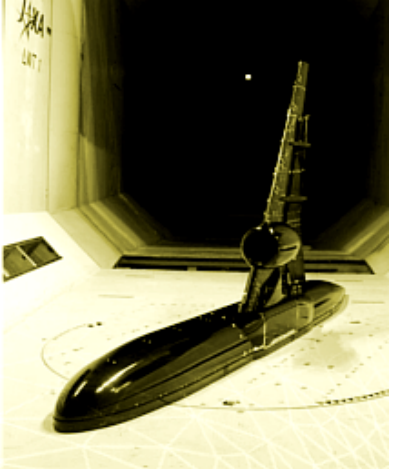


CFD High Lift Prediction Workshop

# Statistical Results

compiled by the HiLiftPW Committee

# Overview

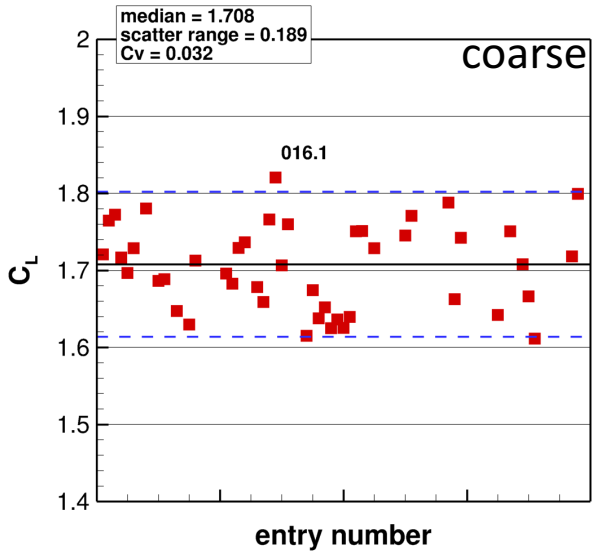


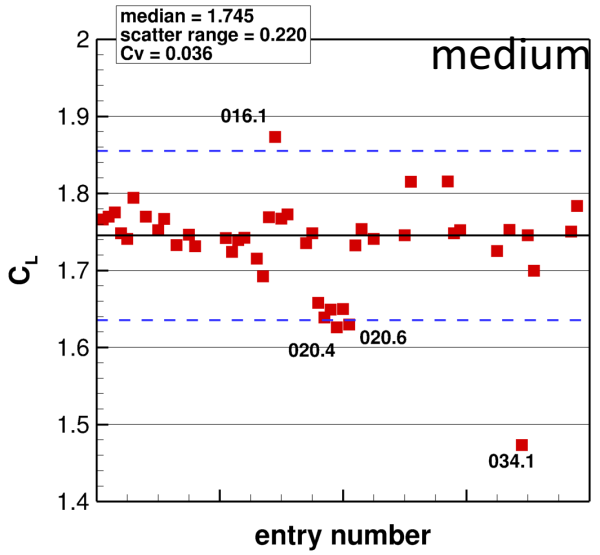
- Used basic method from previous DPW & HiLiftPW workshops
- Limits $\hat{\mu} \pm K\hat{\sigma}$
  - $\hat{\mu}$ = median of sorted data
  - $\hat{\sigma}$ = standard deviation
  - $K = \sqrt{3}$ = coverage factor
- Coefficient of variation Cv = $\hat{\sigma} / \hat{\mu}$
- "Outliers" that fall outside of scatter range are highlighted

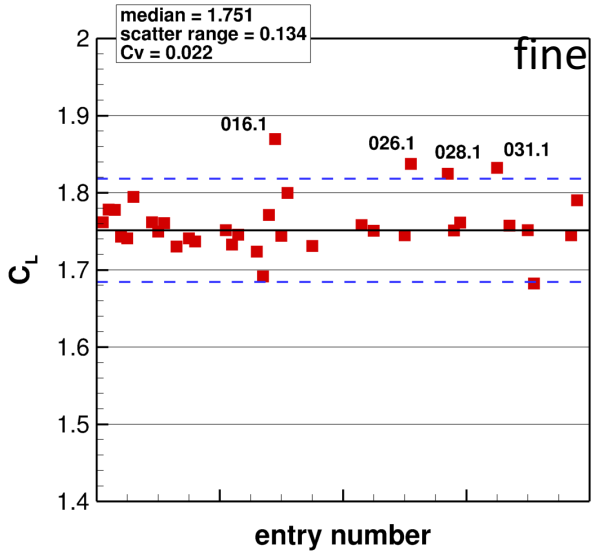
Caveat: the submitted results were analyzed AS IS; some participants may have errors, missing data, etc. that will be corrected later

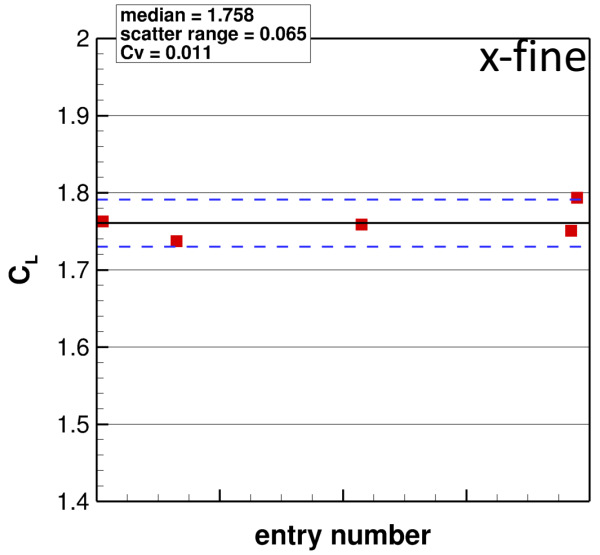
# HL-CRM $C_L$ statistics, Case 1a, alpha=8 deg.





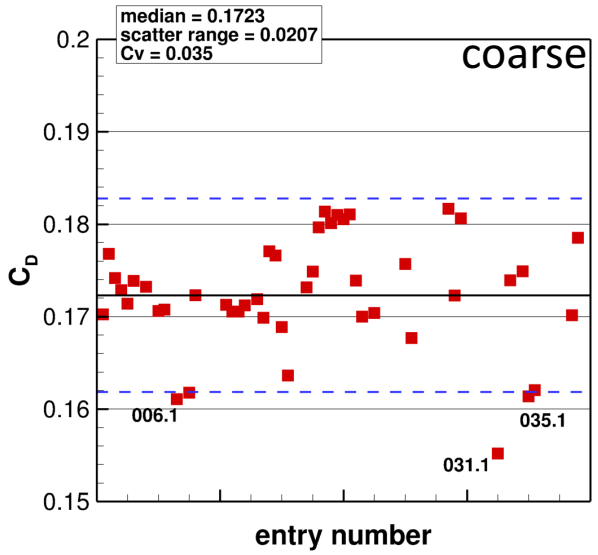



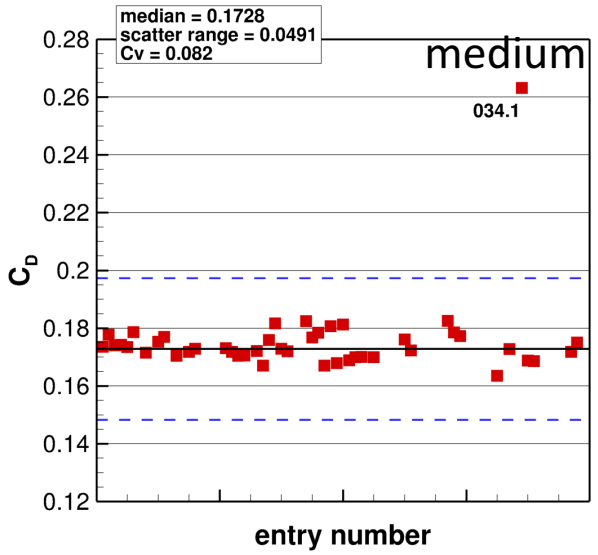



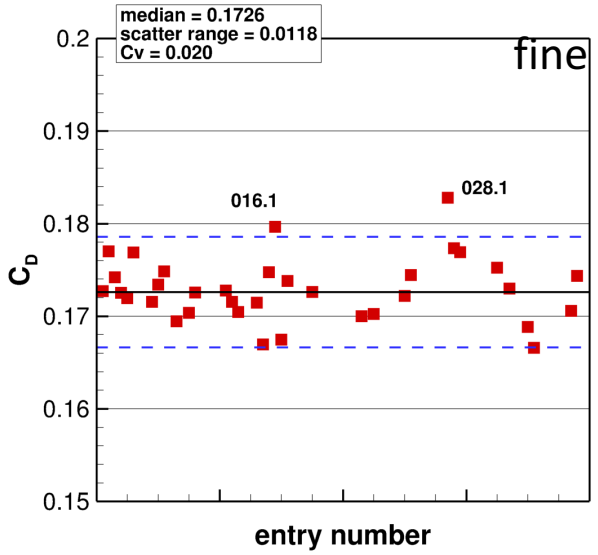



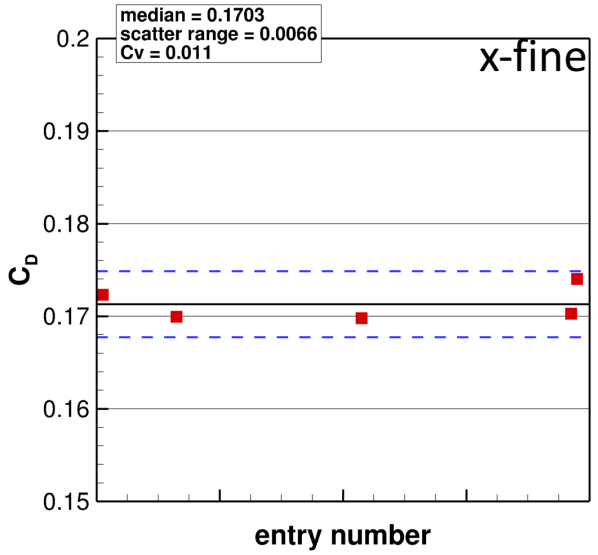
# HL-CRM $C_D$ statistics, Case 1a, alpha=8 deg.





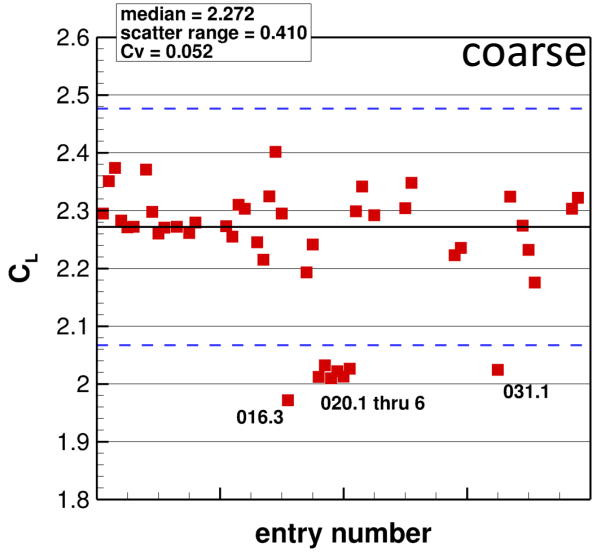



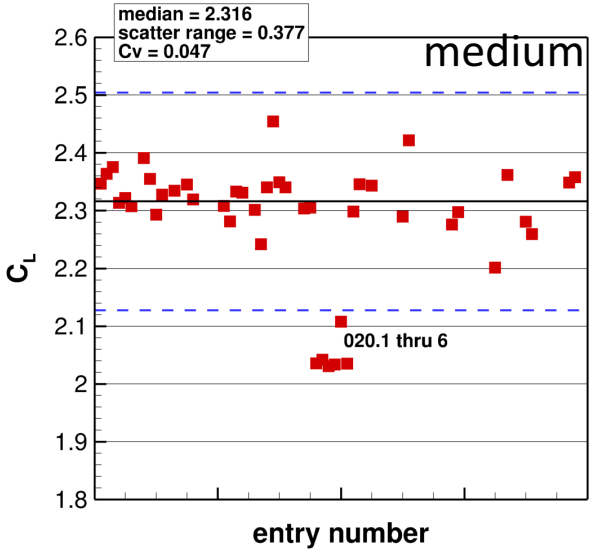



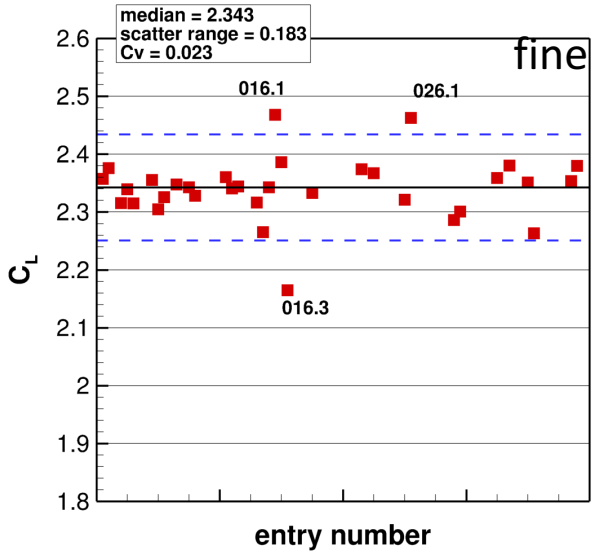



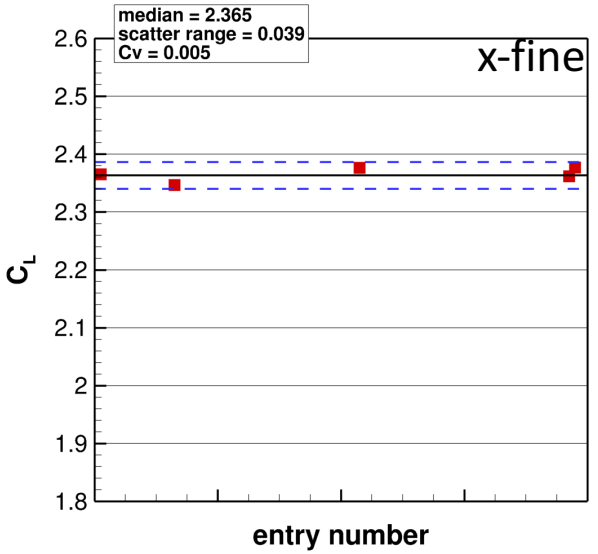
# HL-CRM $C_L$ statistics, Case 1a, alpha=16 deg.





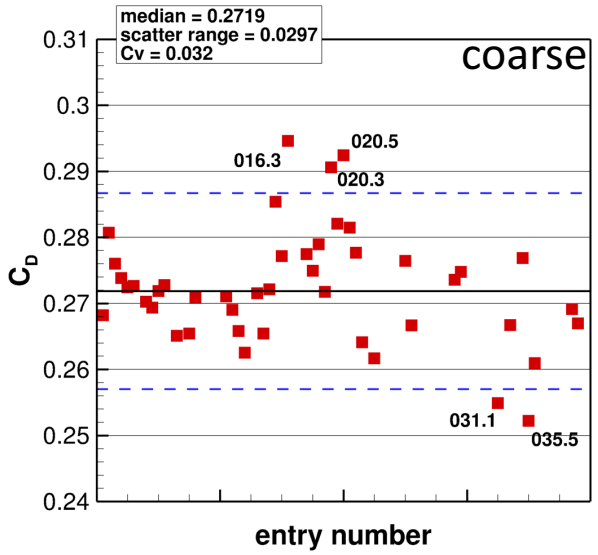



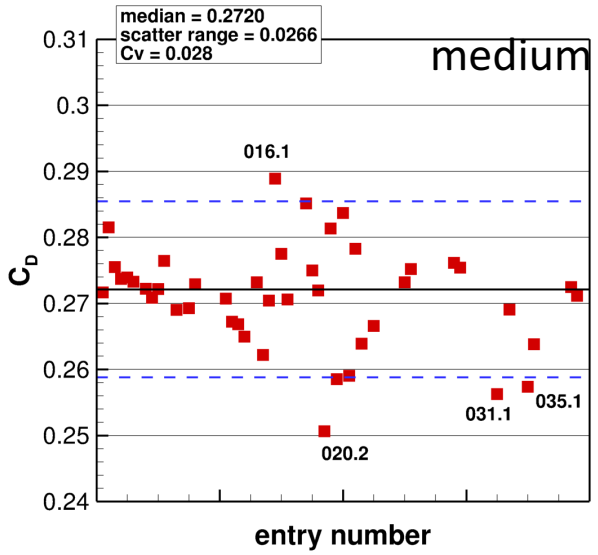



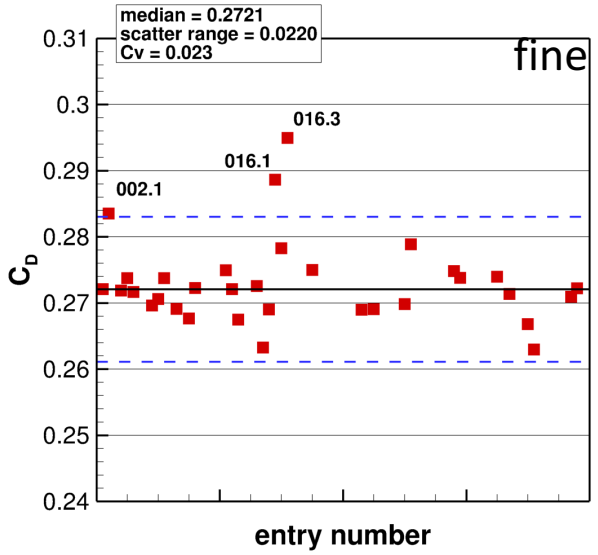



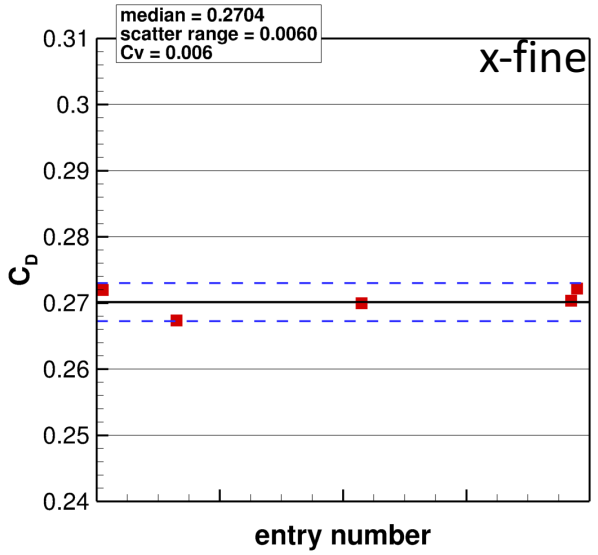
# HL-CRM $C_D$ statistics, Case 1a, alpha=16 deg.





# HL-CRM coefficient of variation
## (Case 1a, “fine” grid)

AIAA CFD High Lift Prediction Workshop

| Case | Unstr “F” grid sizes | Cv for lift | Cv for drag |
|---|---|---|---|
| HiLiftPW-1, alpha=13 | 31-162 M points | 0.014 | 0.021 |
| HiLiftPW-1, alpha=28 | | 0.017 | 0.020 |
| | | | |
| HiLiftPW-2, alpha=7 | 73-177 M points | 0.025 | 0.020 |
| HiLiftPW-2, alpha=16 | | 0.023 | 0.028 |
| | | | |
| HiLiftPW-3, alpha=8 | 70-189 M points | 0.022 | 0.020 |
| HiLiftPW-3, alpha=16 | | 0.023 | 0.023 |

**No noteworthy decrease in Cv over the course of the 3 workshops (but the “F” grids have not gotten much finer, either!)**

# HL-CRM: What about the Xfine grid results?



- 5 participants using Xfine grids appeared to be much more consistent
  - Cv around 0.01 range – about half!
  - Across 4 different codes
  - All used SA-type turbulence model

| PID | Code | Grid | # unknowns | Turb model |
|---|---|---|---|---|
| 001.1 | Mflow | B3 | 397 M | SA |
| 006.1 | CFD++ | B2 | 541 M | SA-RC-QCR |
| 022.1 | OVERFLOW | A | 565 M | SA-RC-QCR |
| 039.1 | FUN3D | B2 | 206 M | SA |
| 040.1 | OVERFLOW | A | 565 M | SA-noft2 |

# JSM $C_L$ & $C_D$ statistics, Case 2a, alpha=4.36 deg.

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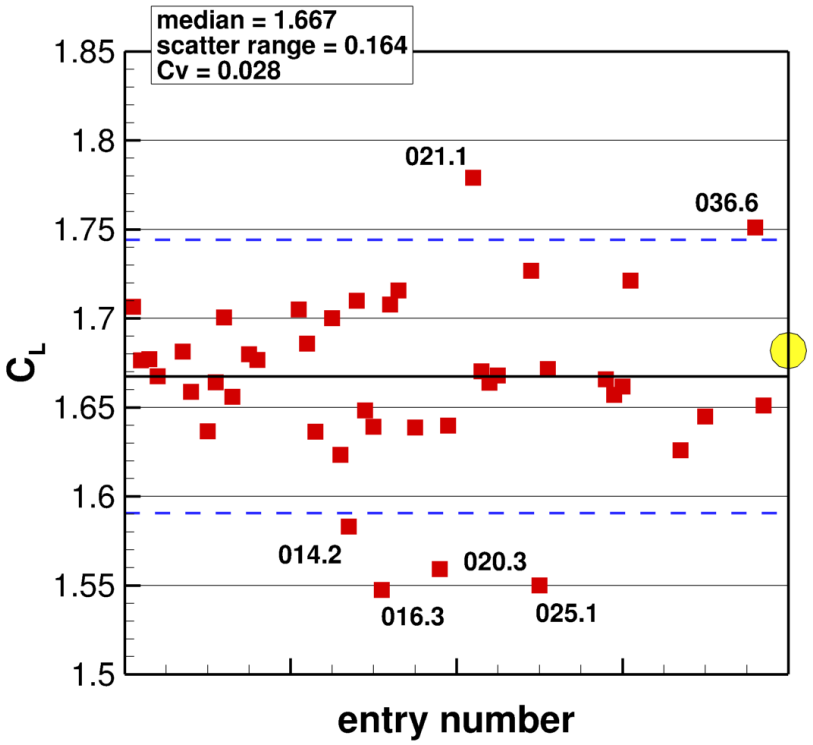
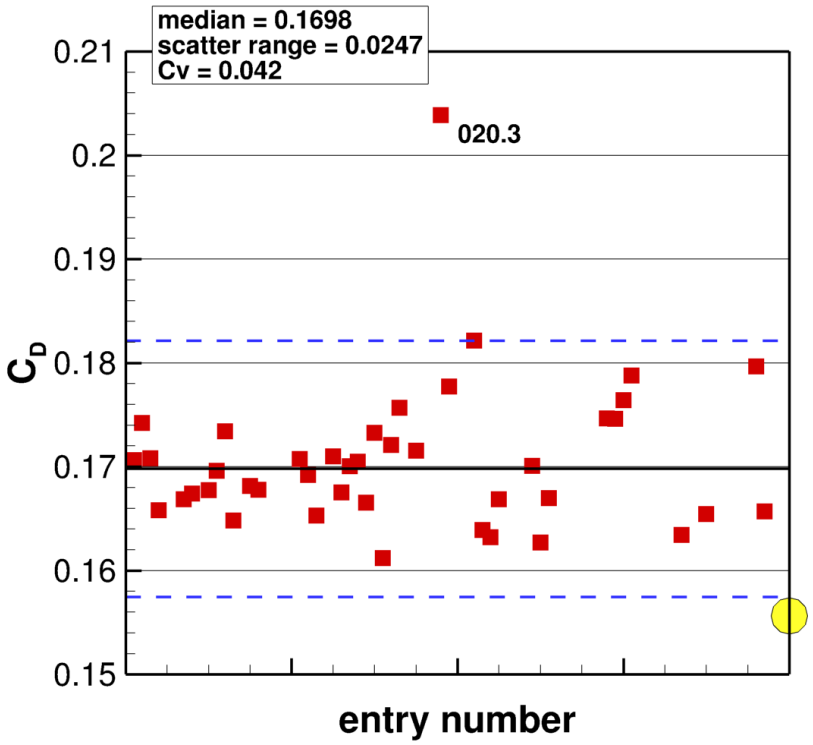
No nacelle/pylon

lift




drag



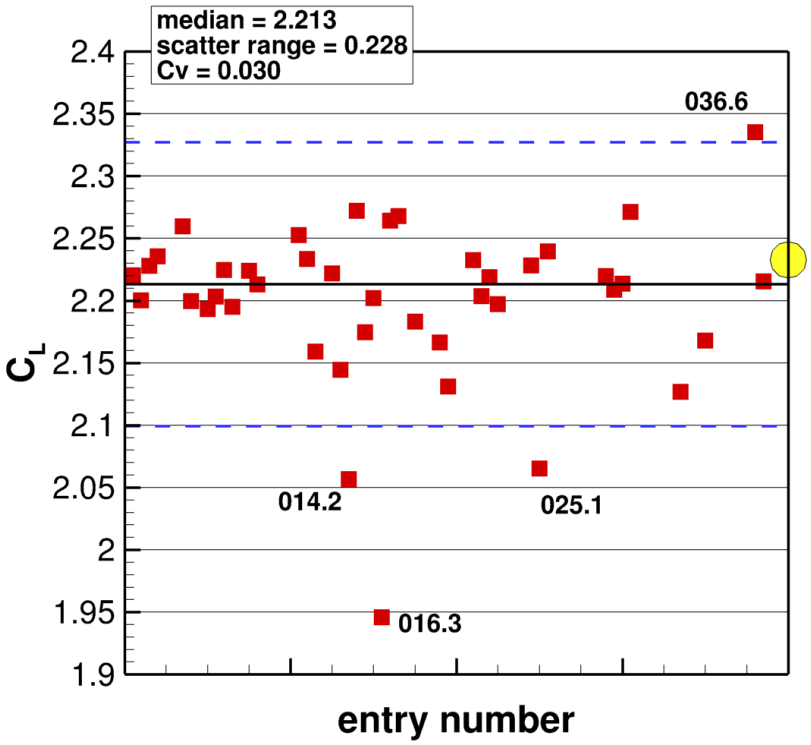

Yellow circle represents experiment

# JSM $C_L$ & $C_D$ statistics, Case 2a, alpha=10.47 deg.

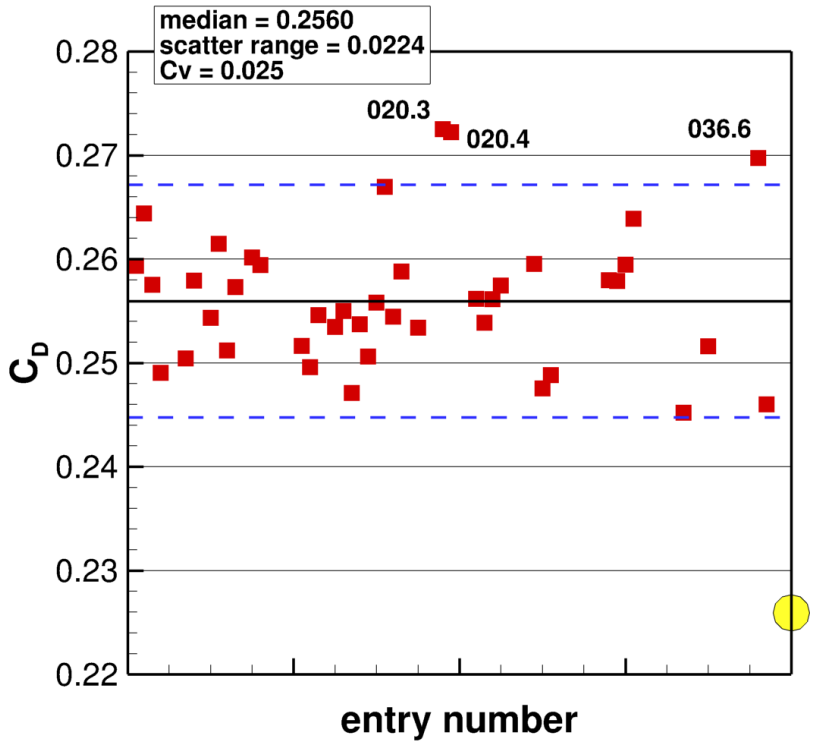
CFD High Lift Prediction Workshop

No nacelle/pylon

lift




drag

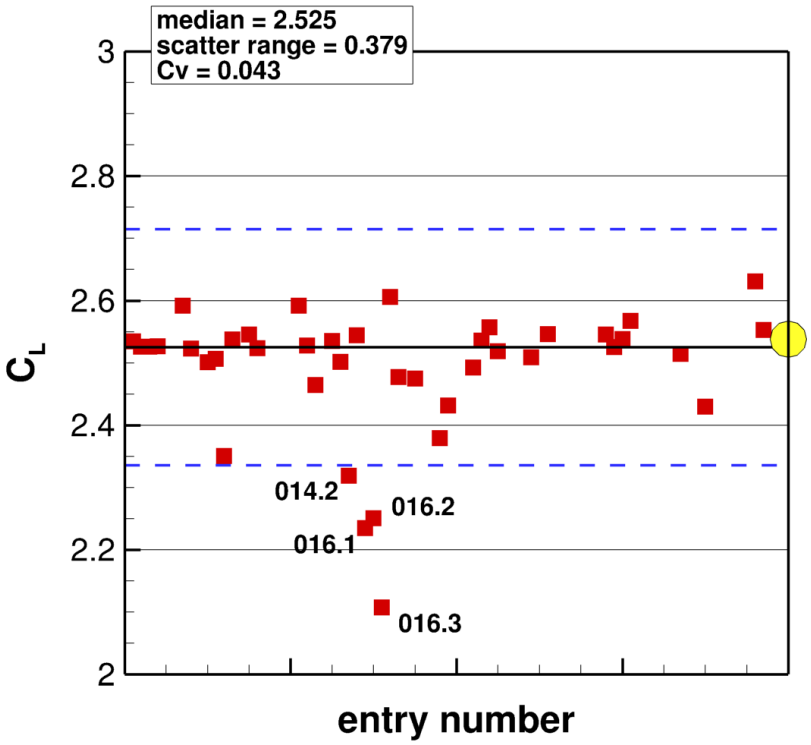


# JSM $C_L$ & $C_D$ statistics, Case 2a, alpha=14.54 deg.

CFD High Lift Prediction Workshop

No nacelle/pylon

lift

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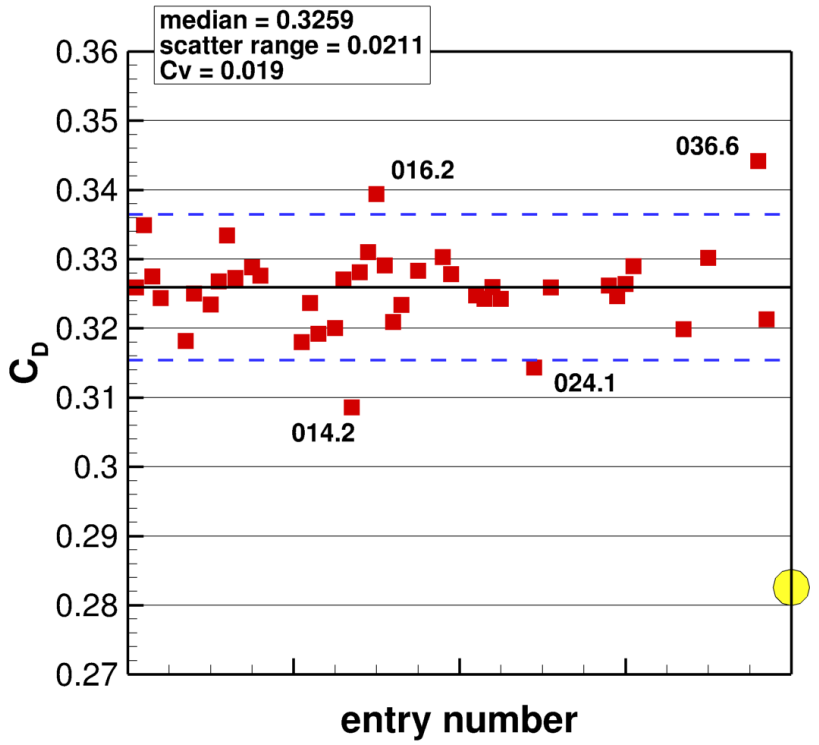
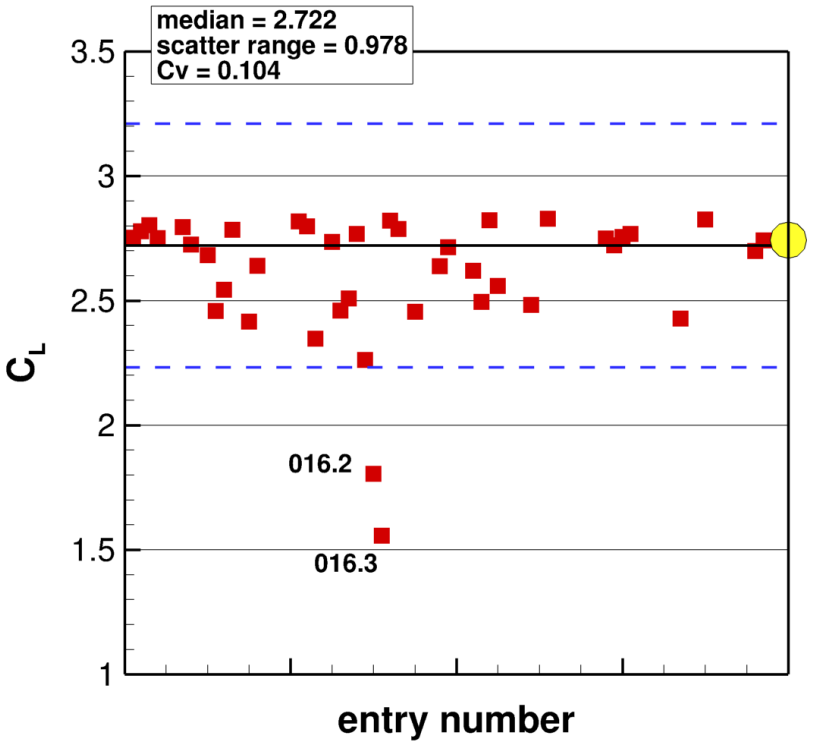


# JSM $C_L$ & $C_D$ statistics, Case 2a, alpha=18.58 deg.

CFD High Lift Prediction Workshop

No nacelle/pylon

lift

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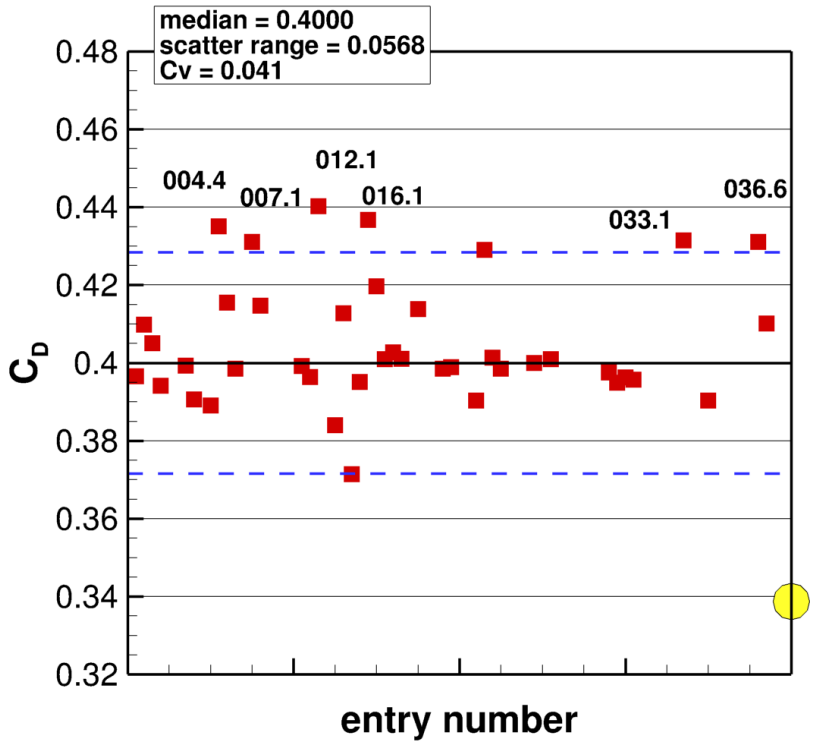
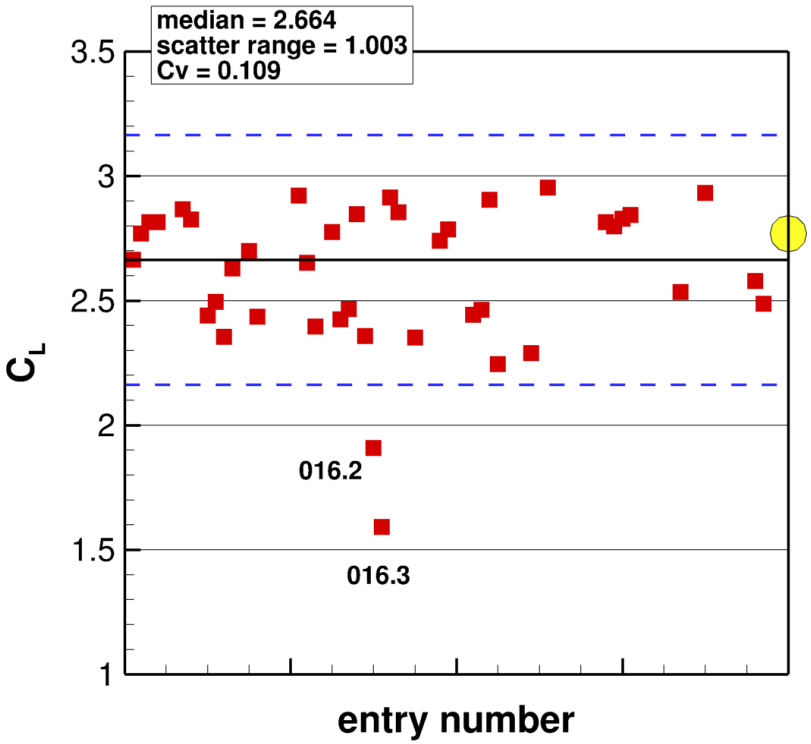


# JSM $C_L$ & $C_D$ statistics, Case 2a, alpha=20.59 deg.

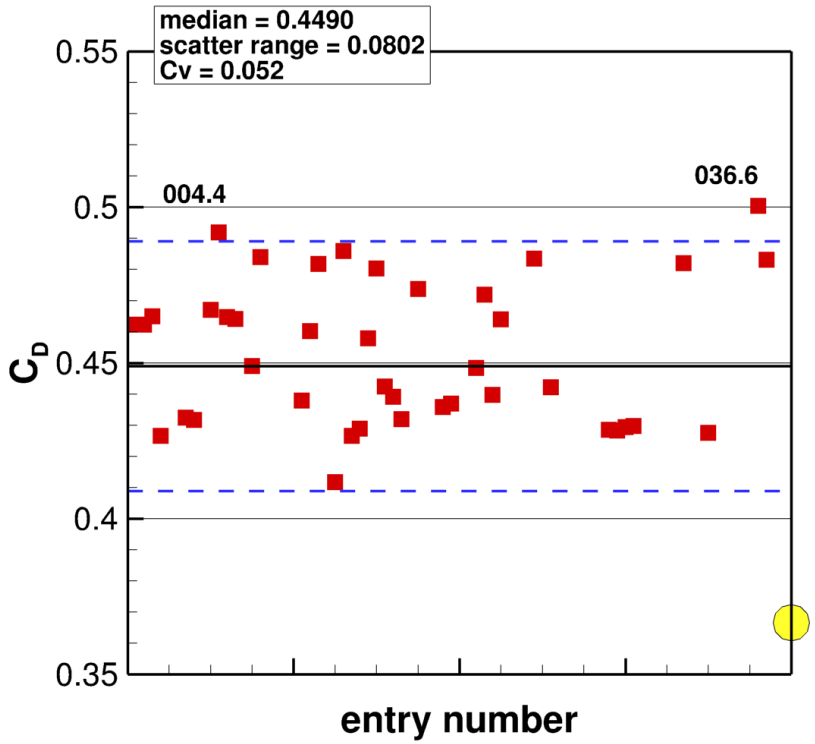
CFD High Lift Prediction Workshop

No nacelle/pylon

lift




drag

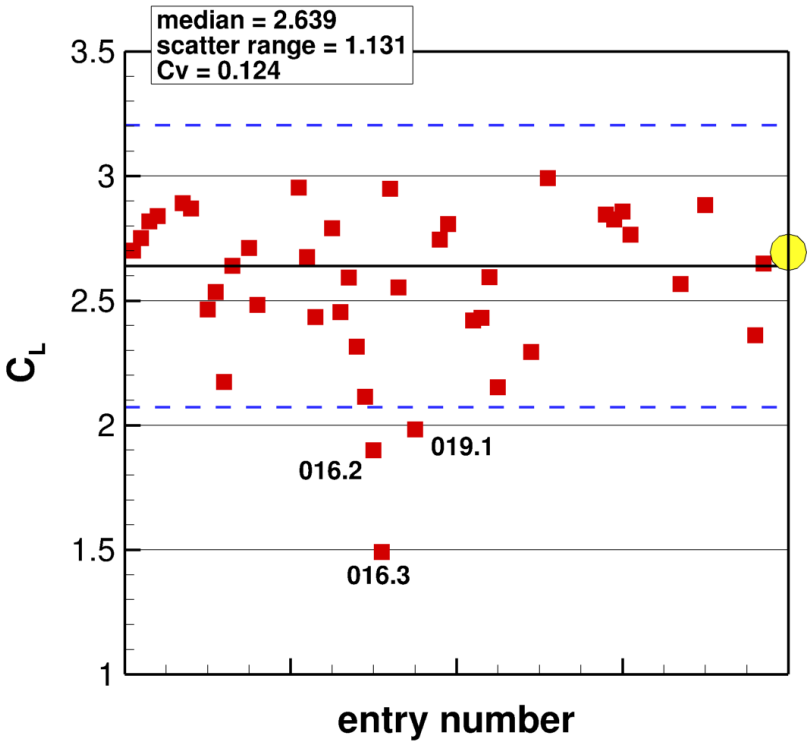


# JSM $C_L$ & $C_D$ statistics, Case 2a, alpha=21.57 deg.

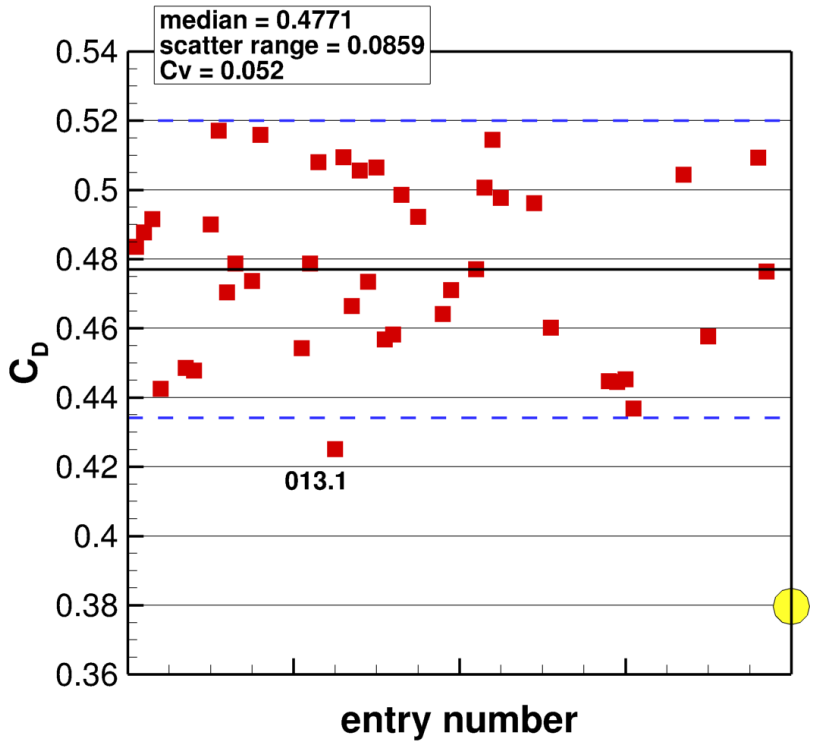
CFD High Lift Prediction Workshop

No nacelle/pylon

lift




drag

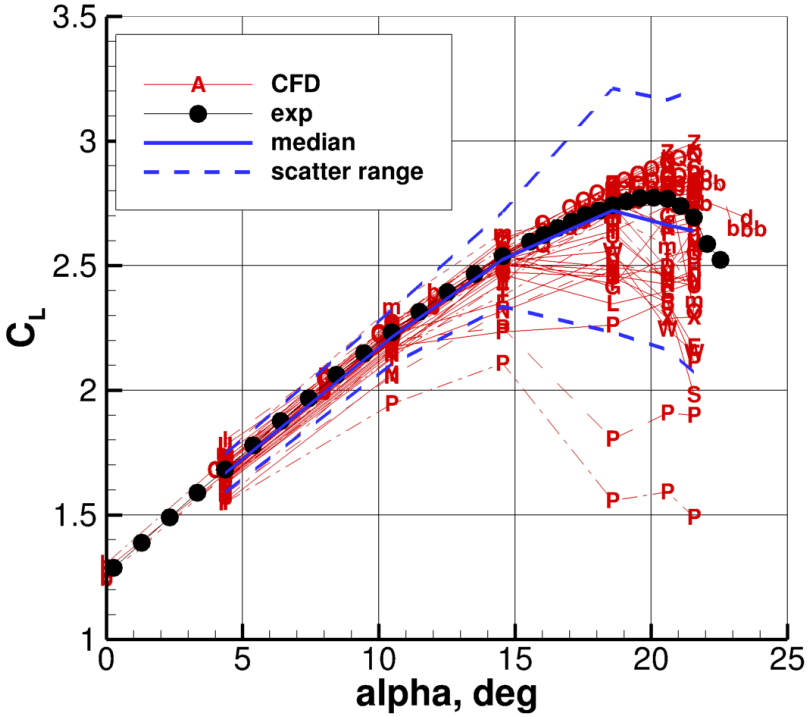


# JSM statistics compared to experiment

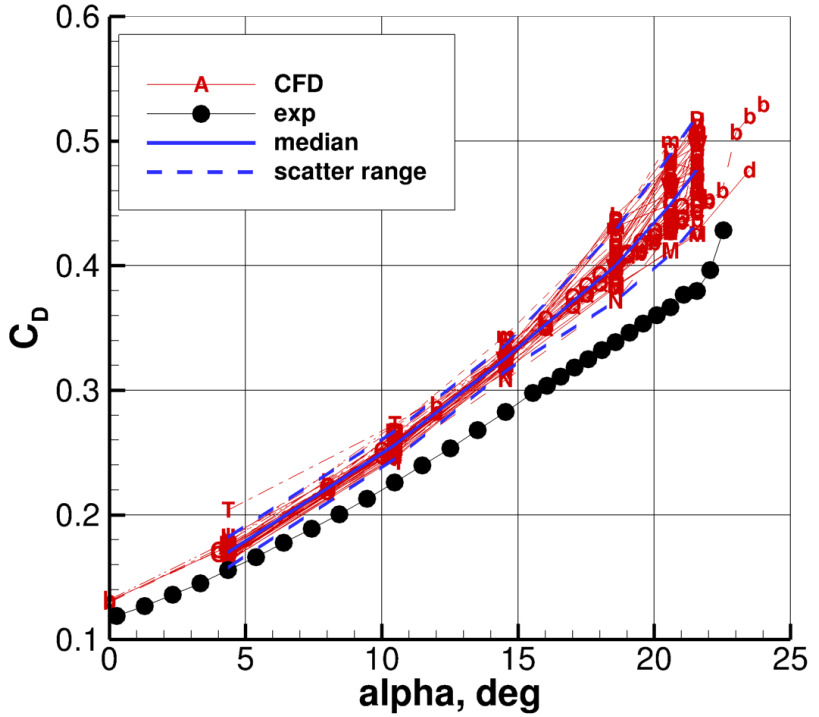
CFD High Lift Prediction Workshop

Case 2a; no nacelle/pylon

lift




drag



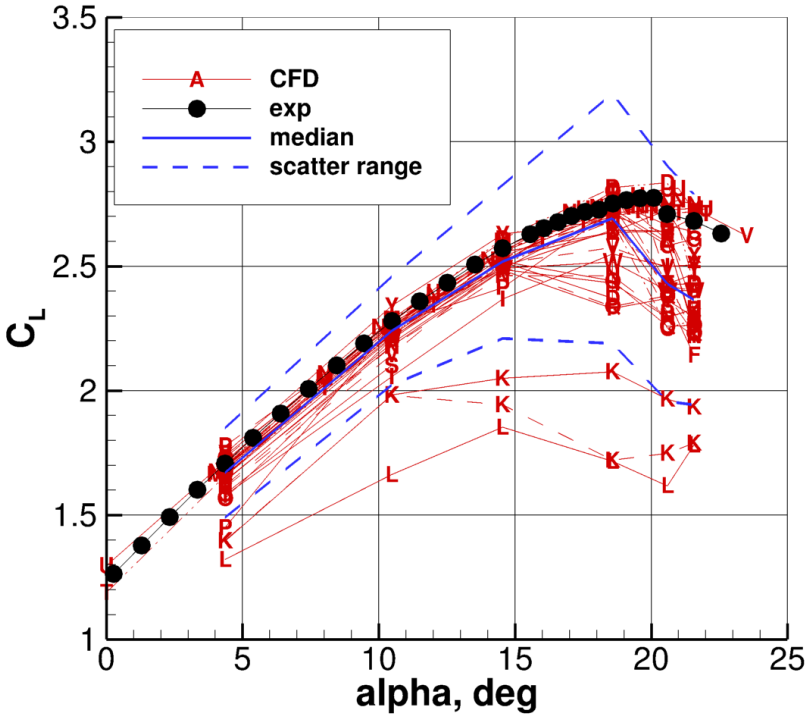

Median $C_L$ matches experiment well (except low at 20.59 deg)
Median $C_D$ is too high

# JSM statistics compared to experiment

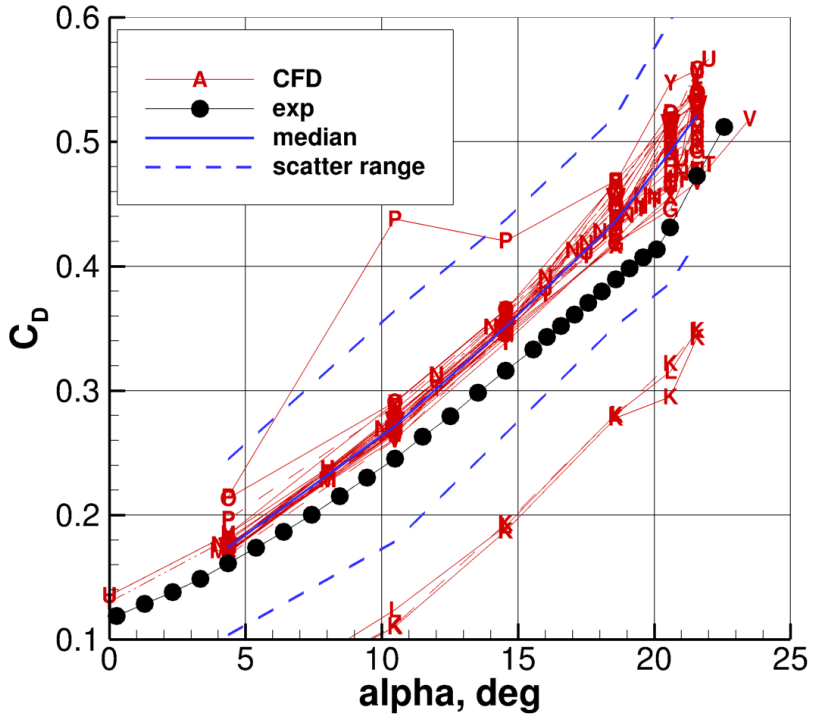
CFD High Lift Prediction Workshop

## Case 2c; with nacelle/pylon

lift




drag




CFD results have more spread when include nacelle/pylon

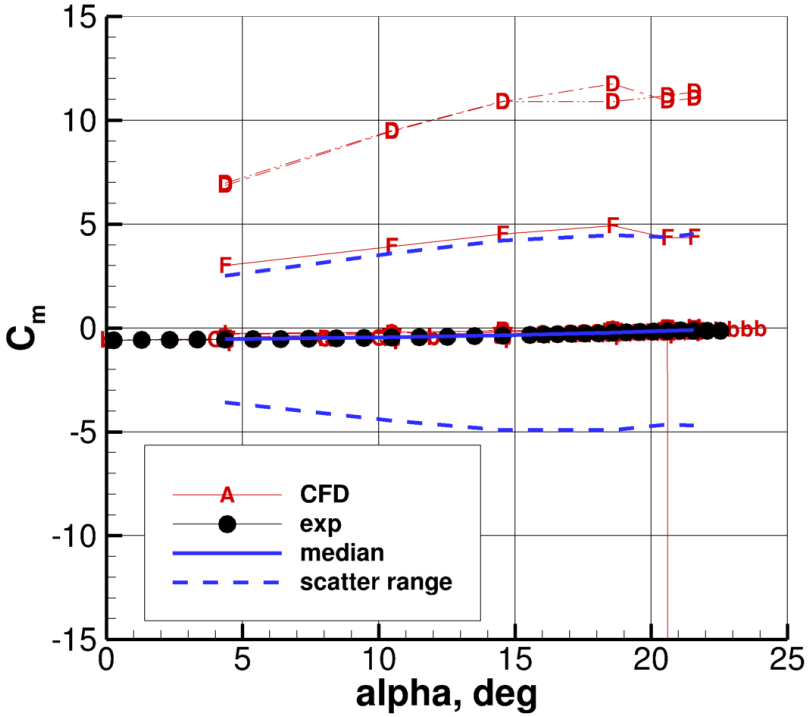
Median $C_L$ now slightly lower than experiment

# JSM statistics compared to experiment

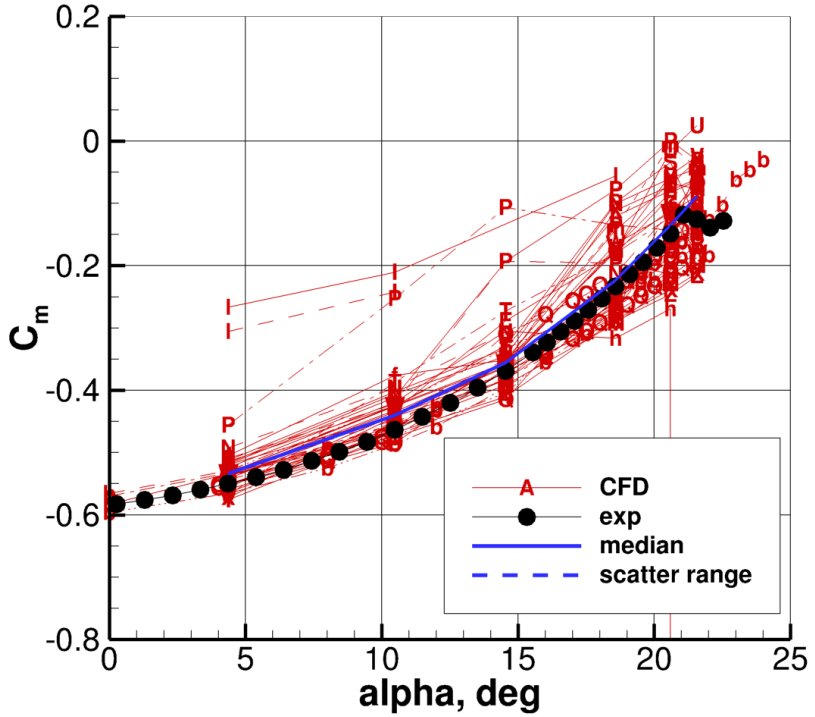
CFD High Lift Prediction Workshop

## Case 2a; no nacelle/pylon

moment




moment (zoom)

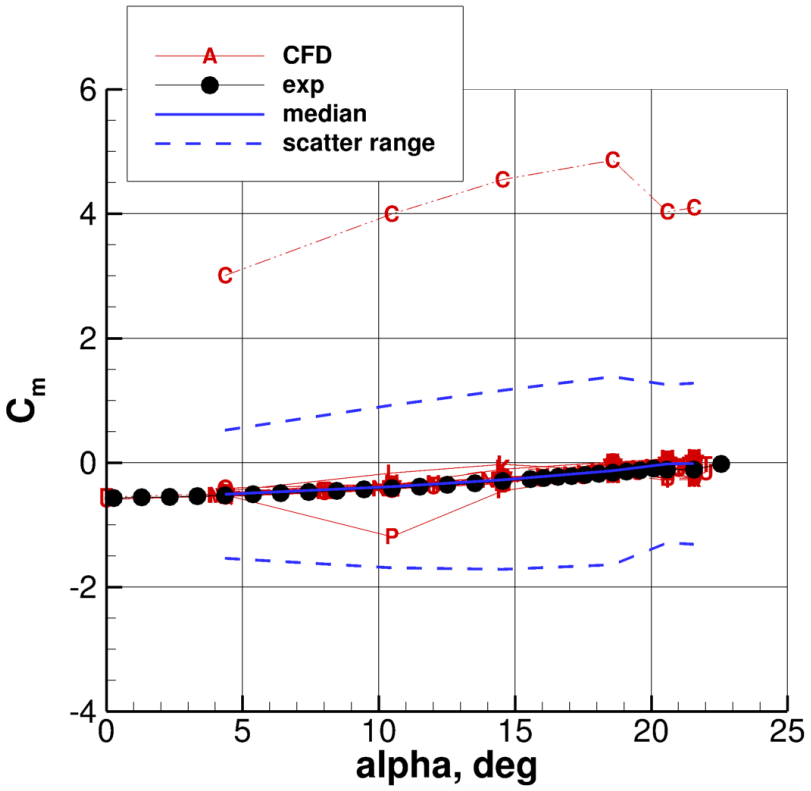


# JSM statistics compared to experiment

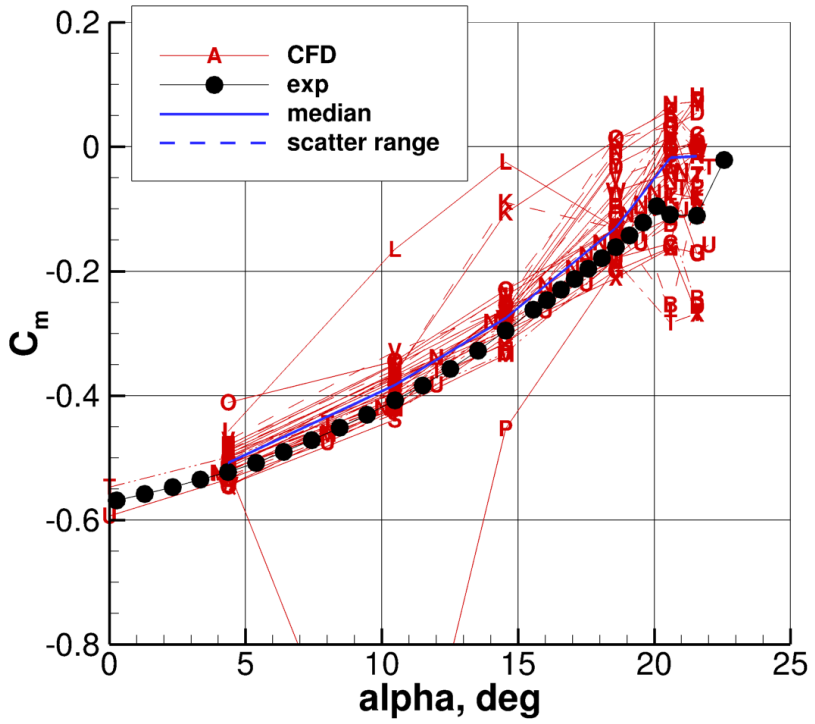
CFD High Lift Prediction Workshop

## Case 2c; with nacelle/pylon

moment




moment (zoom)



# Compare scatter ranges for HL-CRM and JSM



| Model | $C_L$ scatter range / Cv (medium grid) | $C_L$ scatter range / Cv (fine grid) |
|---|---|---|
| HL-CRM, alpha=8 deg | 0.220 / 0.036 | 0.134 / 0.022 |
| JSM, alpha=10.47 deg | 0.228 / 0.030 | |
| JSM n/p, alpha=10.47 deg | 0.435 / 0.056 | |
| | | |
| HL-CRM, alpha=16 deg | 0.377 / 0.047 | 0.183 / 0.023 |
| JSM, alpha=14.54 deg | 0.379 / 0.043 | |
| JSM n/p, alpha=14.54 deg | 0.617 / 0.071 | |

Similar scatter trends between the HL-CRM and JSM (no nacelle/pylon) configurations in linear portion of lift curve

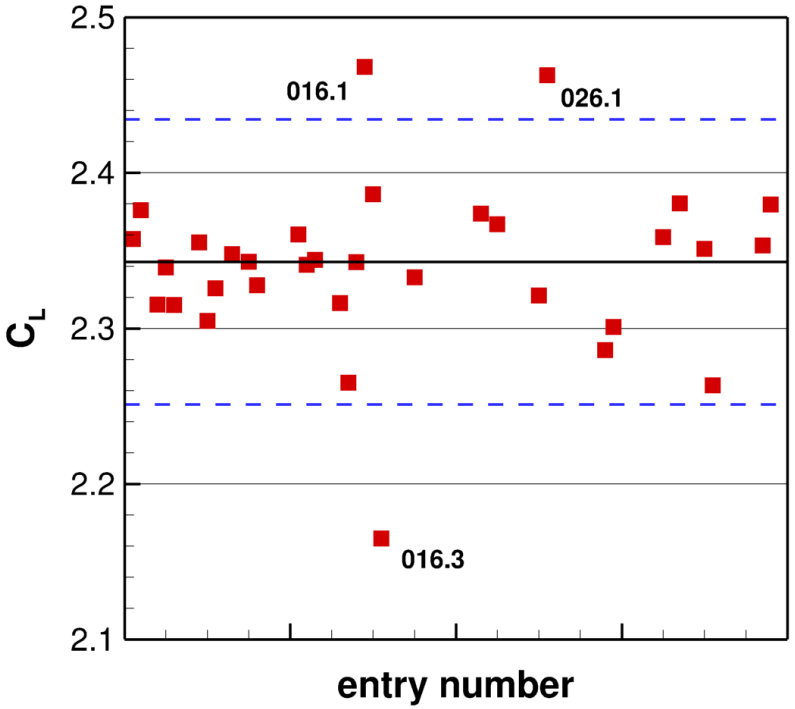
Addition of nacelle/pylon doubles the scatter for JSM

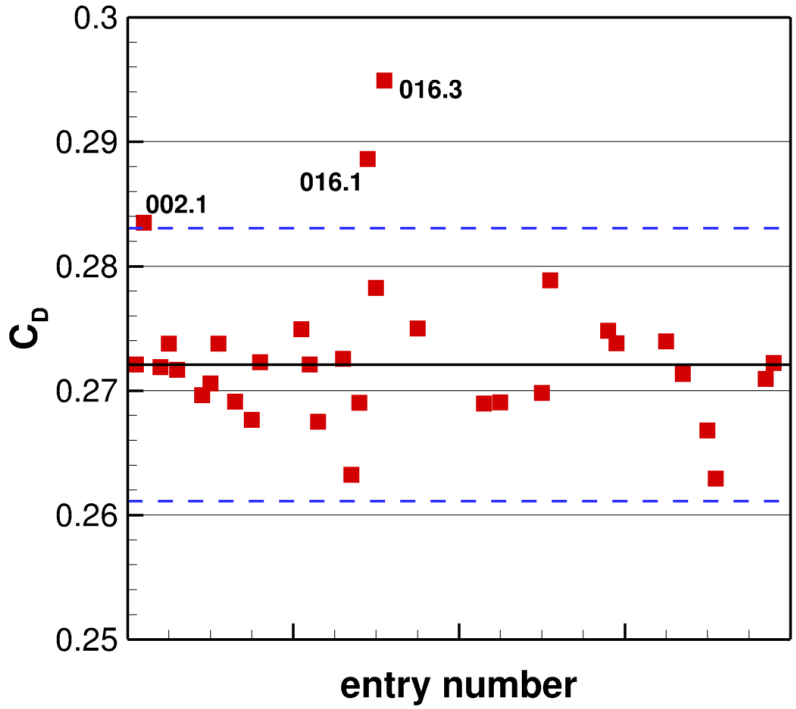
# Look for obvious trends

# HL-CRM – deeper dig



Case 1a, fine grid, alpha=16 deg

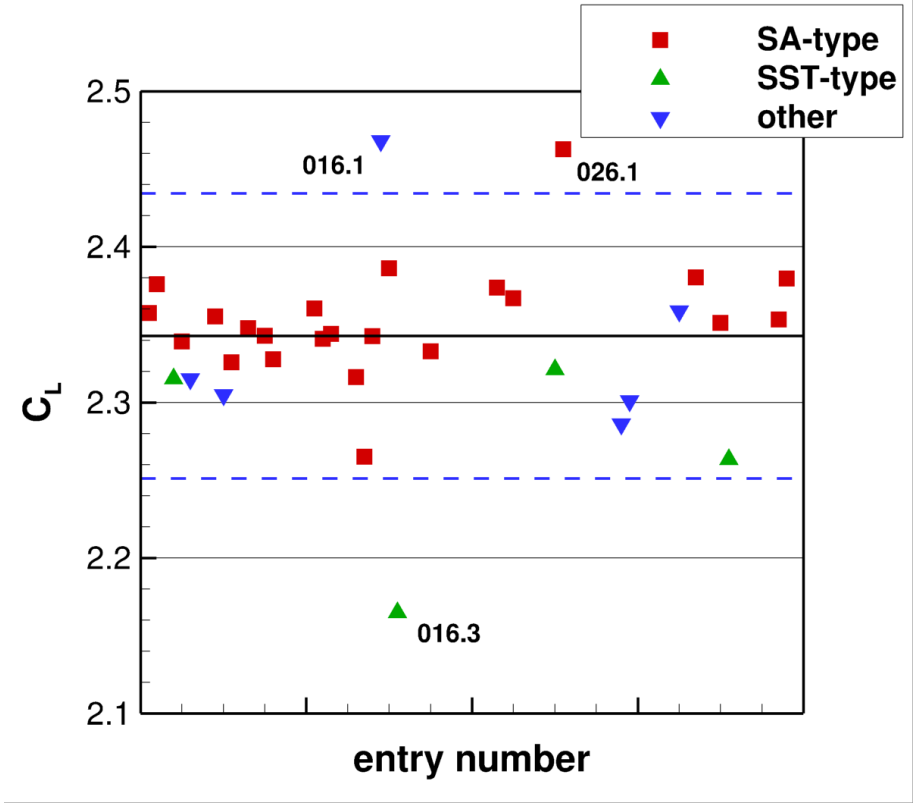


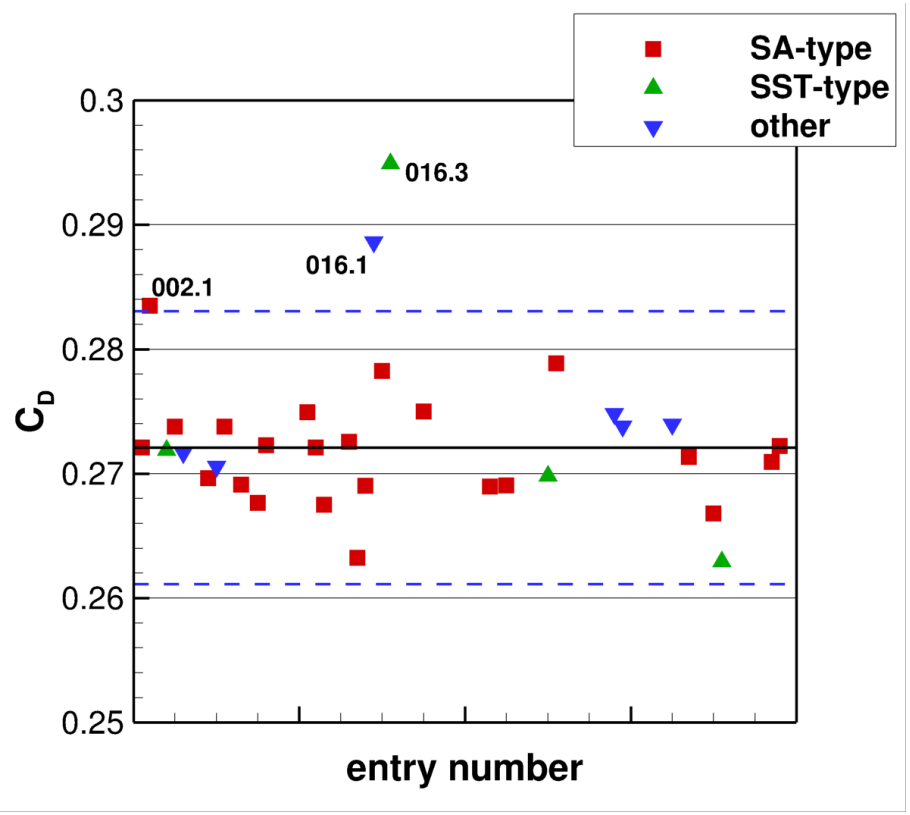



# HL-CRM – deeper dig by turbulence model



## Case 1a, fine grid, alpha=16 deg



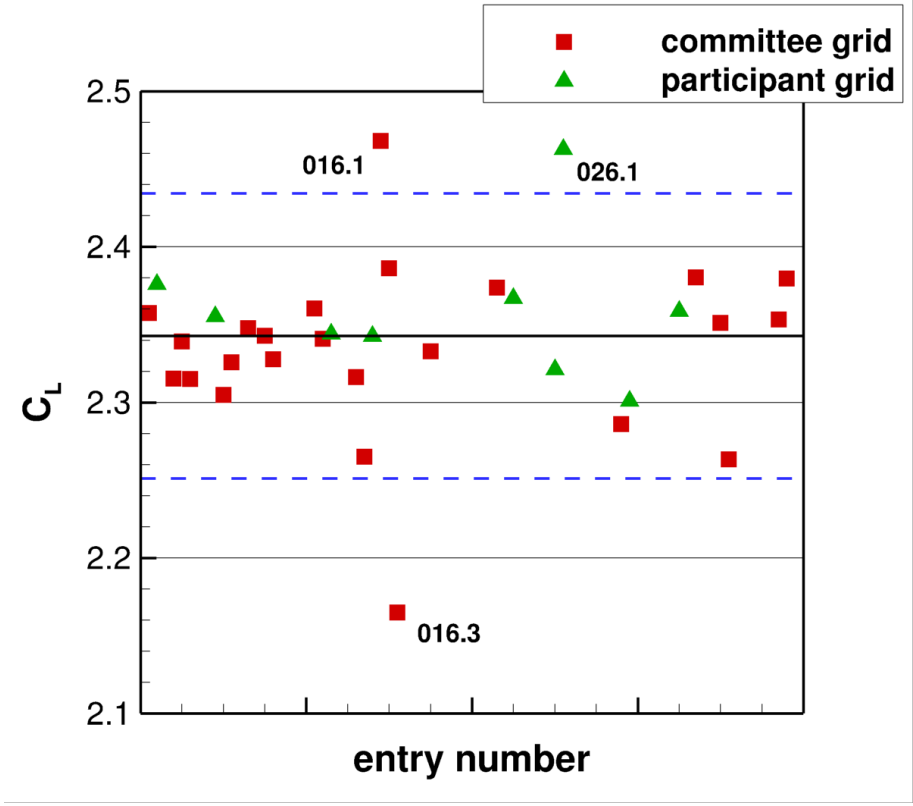



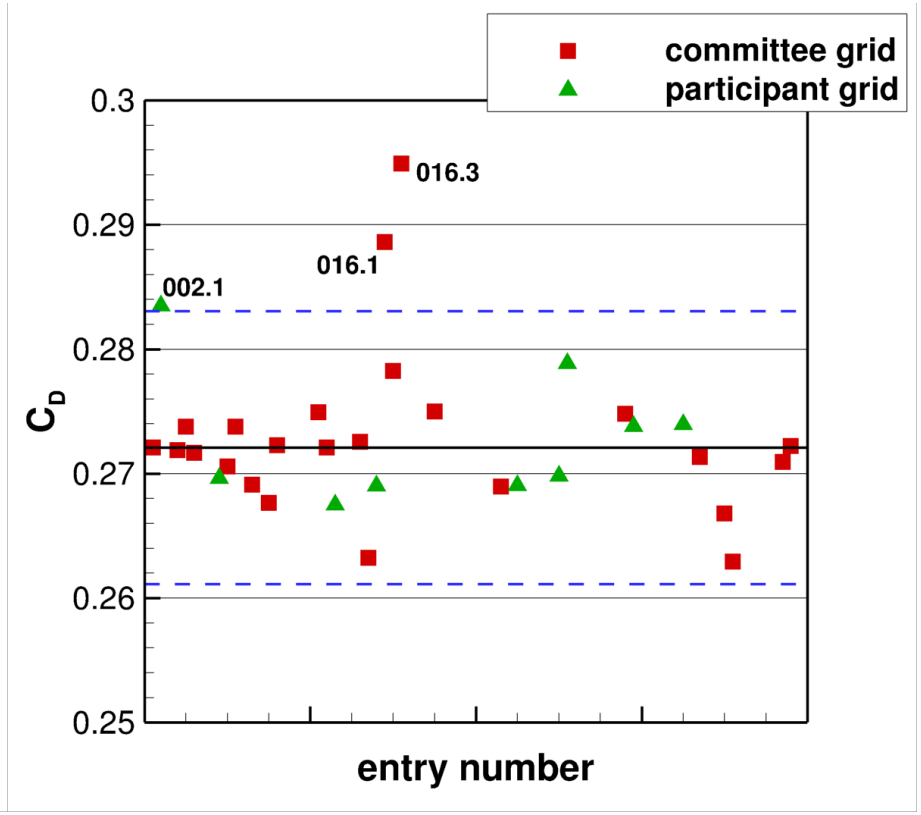

No obvious trends

# HL-CRM – deeper dig by grid



## Case 1a, fine grid, alpha=16 deg



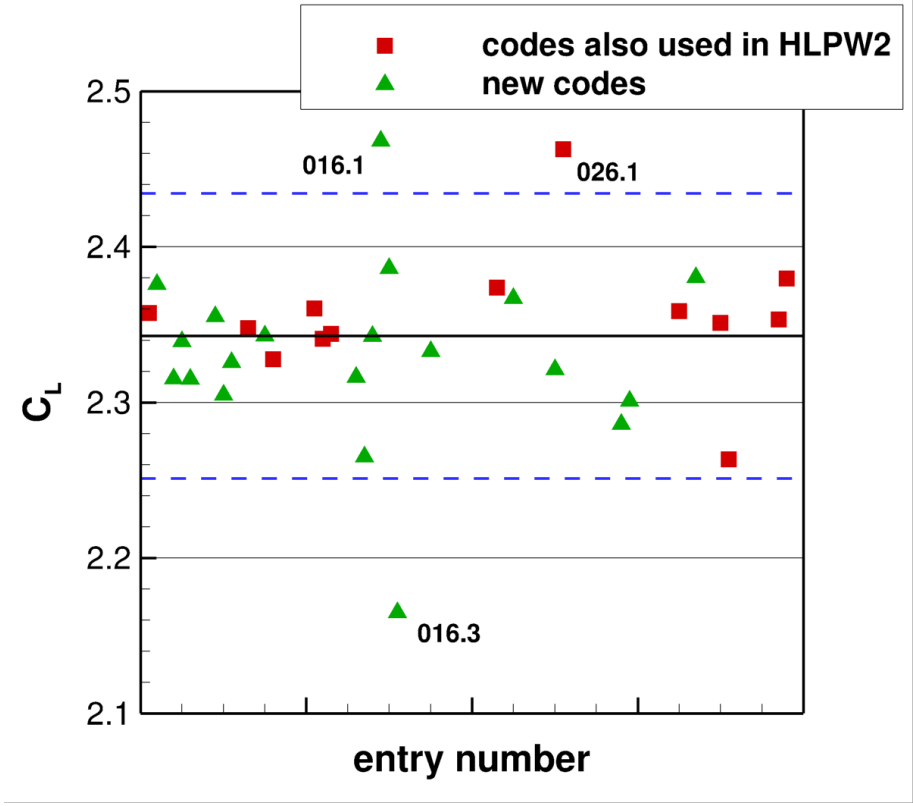



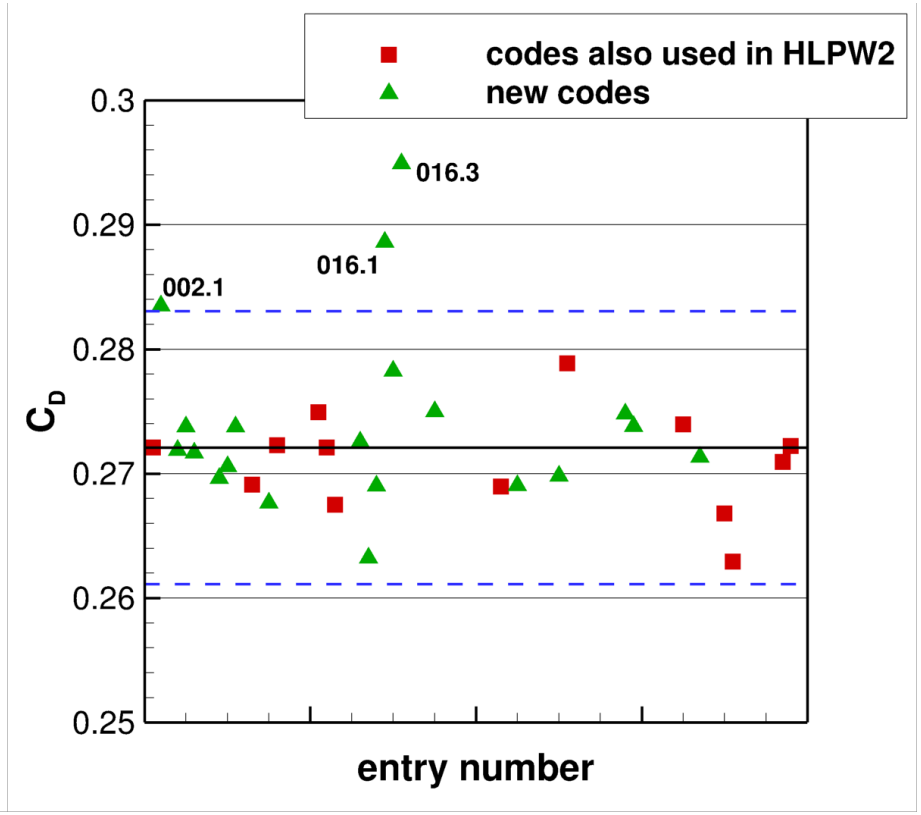

No obvious trends

# HL-CRM – deeper dig by codes from HLPW2



## Case 1a, fine grid, alpha=16 deg



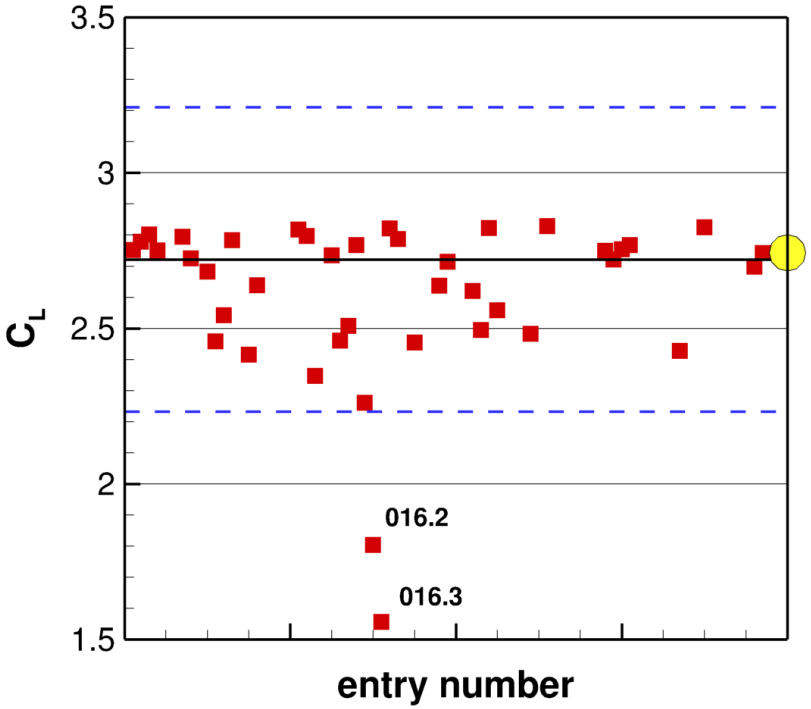



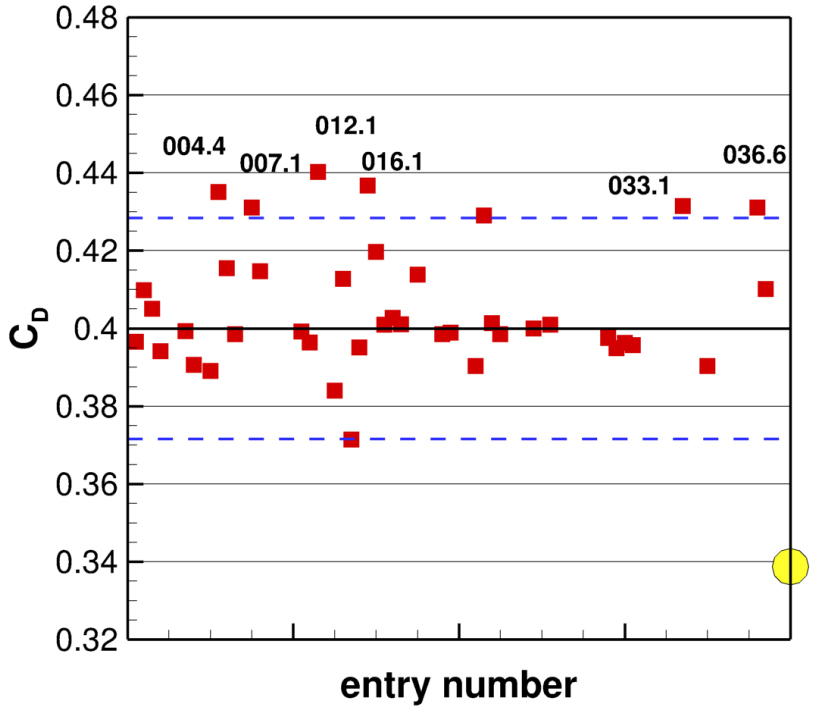

No obvious trends

# JSM – deeper dig



Case 2a, no nacelle/pylon, alpha=18.58 deg



# JSM – deeper dig by turbulence model

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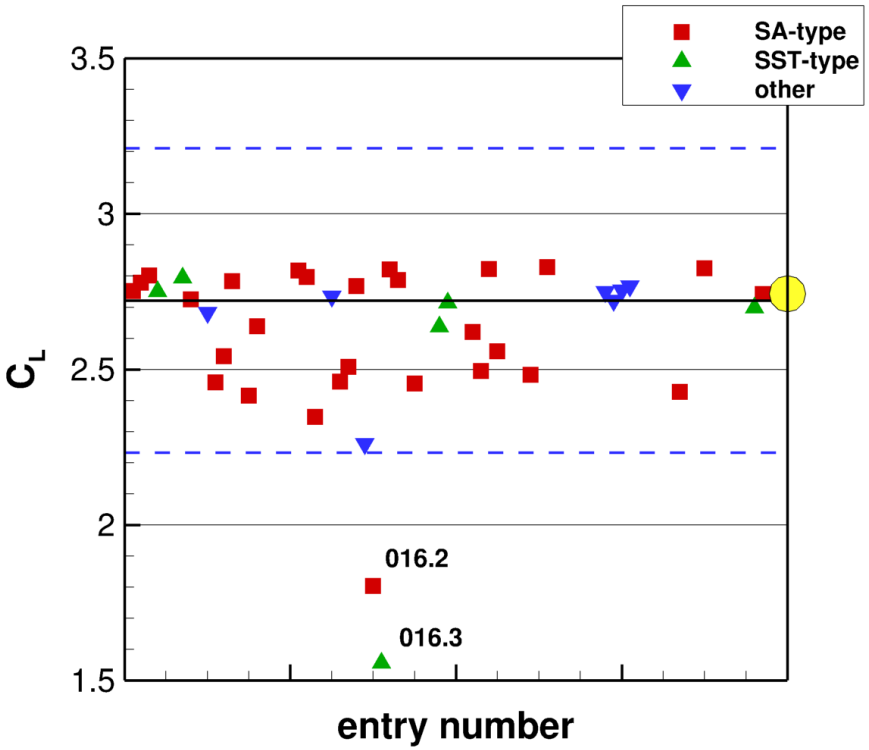
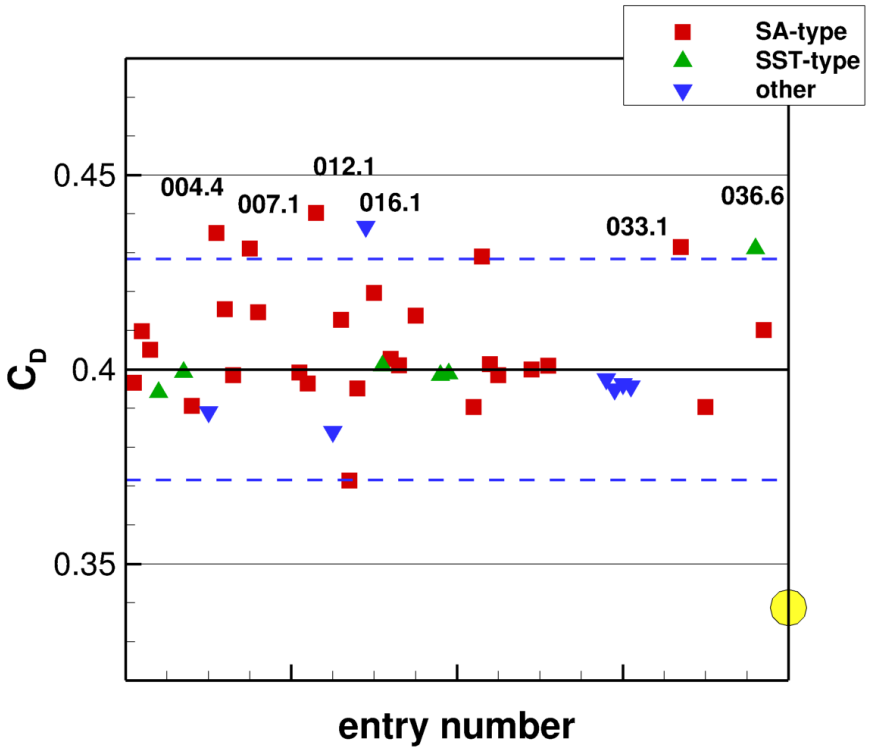
Case 2a, no nacelle/pylon, alpha=18.58 deg



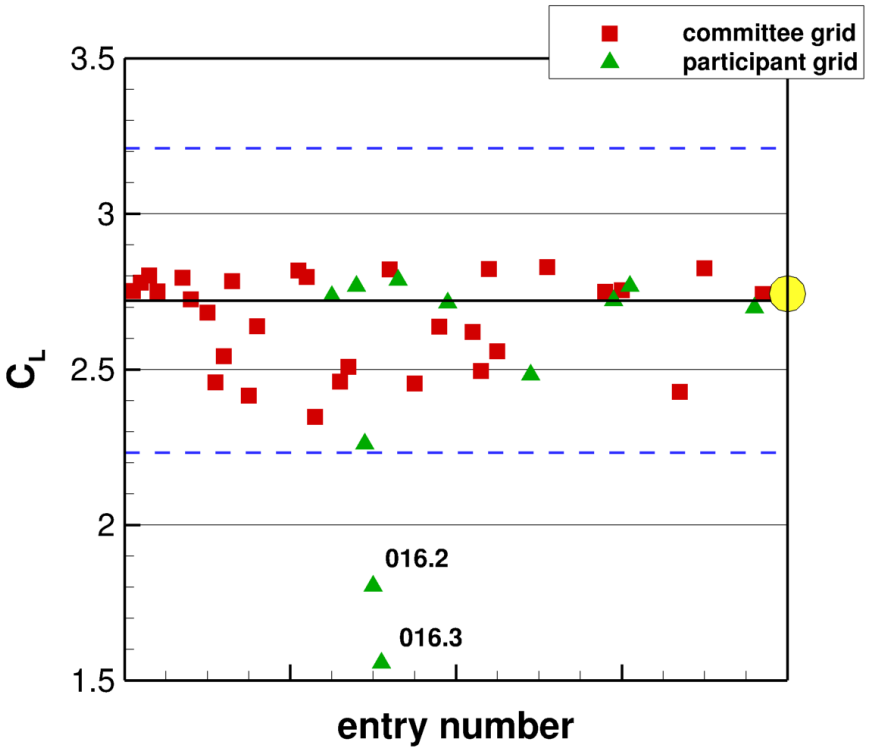



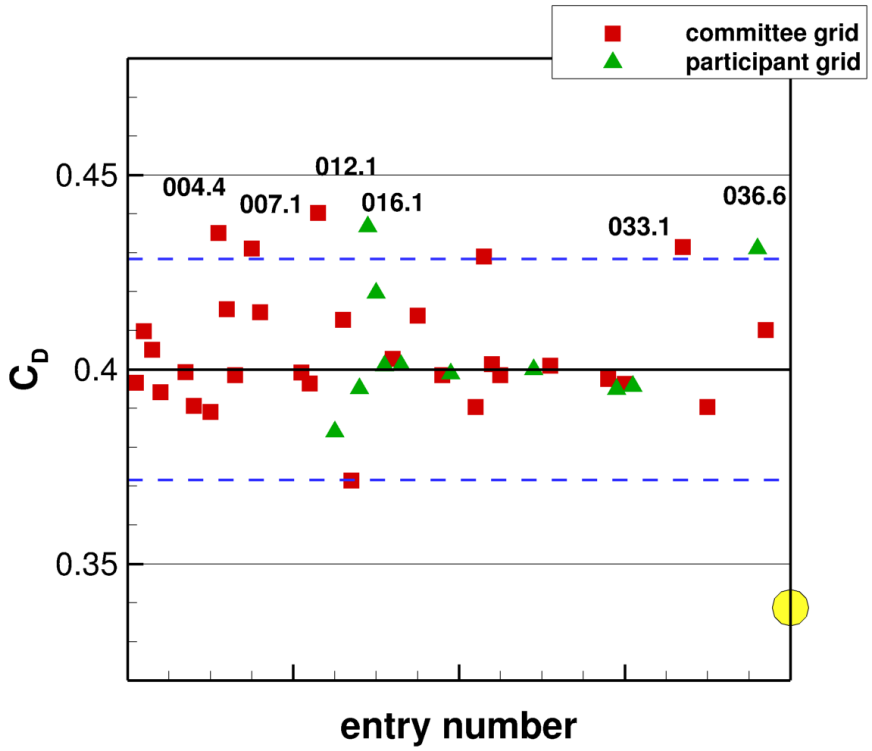

No obvious trends

# JSM – deeper dig by grid



Case 2a, no nacelle/pylon, alpha=18.58 deg



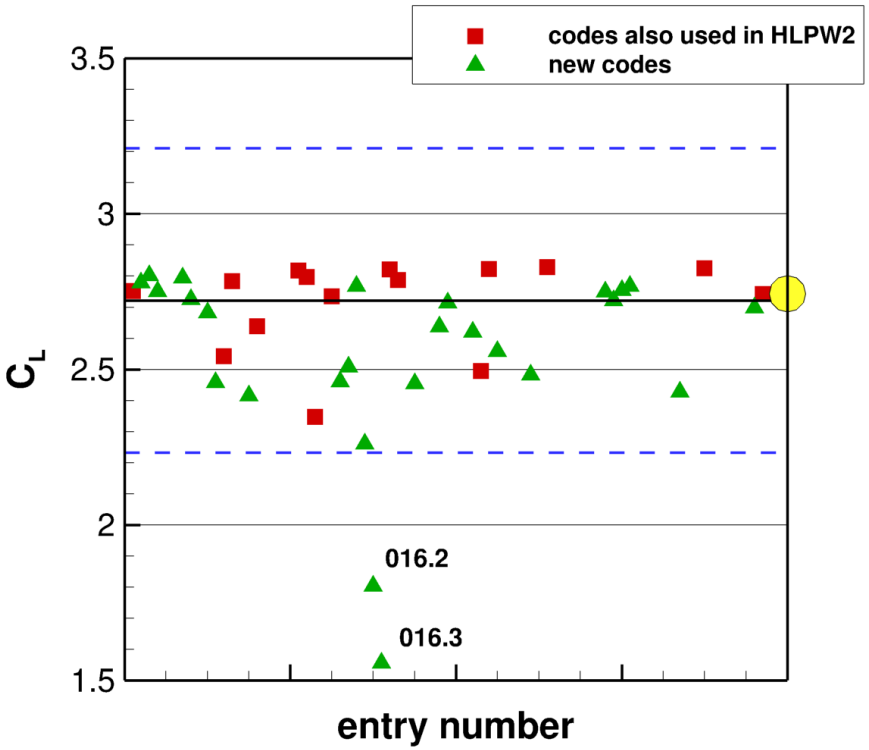



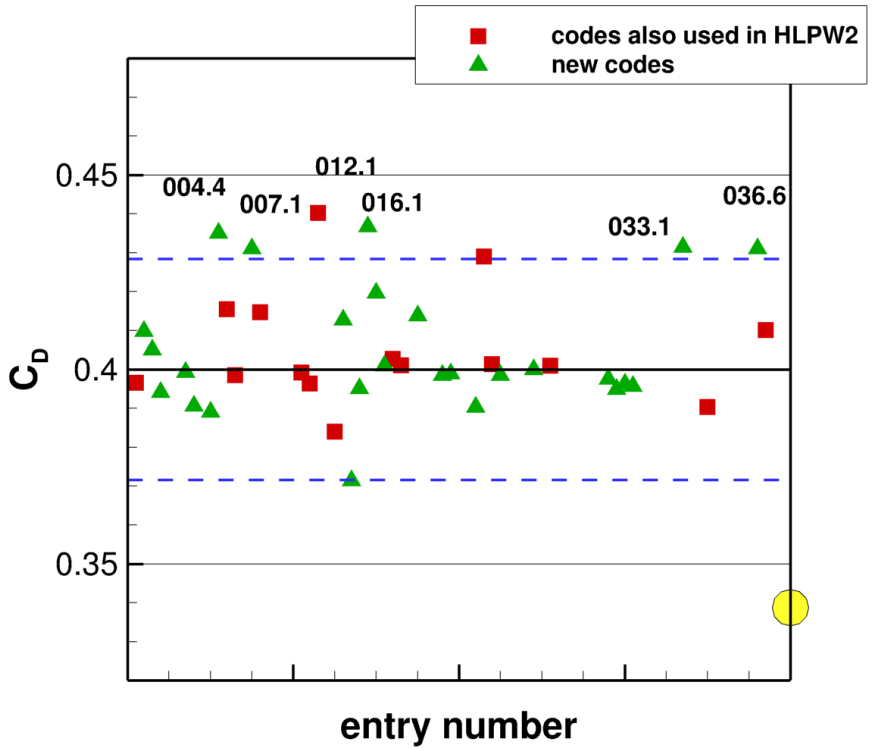

No obvious trends

# JSM – deeper dig by codes from HLPW2

CFD High Lift Prediction Workshop

## Case 2a, no nacelle/pylon, alpha=18.58 deg




No obvious trends

# Summary



- For HL-CRM, CFD shows similar variations as at previous HiLiftPWs (for "Fine" grid)
  - I.e., CFD is not getting any tighter for similar grid sizes
  - X-Fine results (5 participants) appear to show less variation
- CFD's median $C_L$ and $C_m$ agree reasonably well with JSM experiment
- $C_D$ predicted by CFD is significantly higher than JSM experiment
- Serious errors in some $C_m$ participant data for JSM
- The scatter range on medium grid for JSM (experiment available) is similar to those for HL-CRM (blind case)
  - I.e., no trend to indicate "cheating" or "tuning" because of known answer
  - Near $C_{L,max}$ the scatter range for CFD is much larger than it is at low alphas
  - Adding nacelle/pylon doubles the $C_L$ scatter range at low alphas
- There are no obvious trends here:
  - By turbulence model type
  - By committee vs. non-committee grid
  - By codes used in HLPW2 vs. new codes
- Following 2 talks will also look for trends

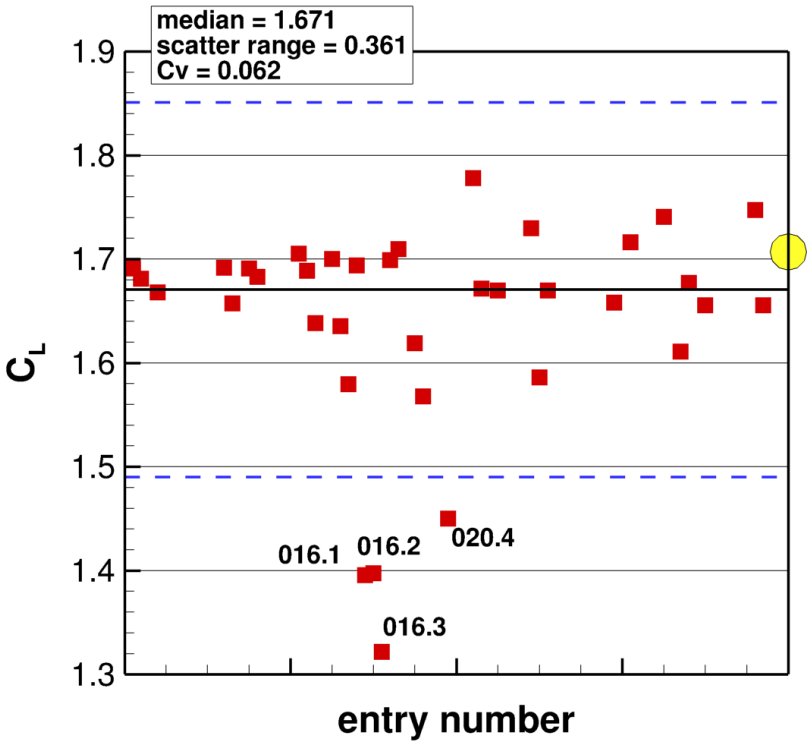
# Backup slides

# JSM $C_L$ & $C_D$ statistics, Case 2c, alpha=4.36 deg.

CFD High Lift Prediction Workshop

With nacelle/pylon

lift

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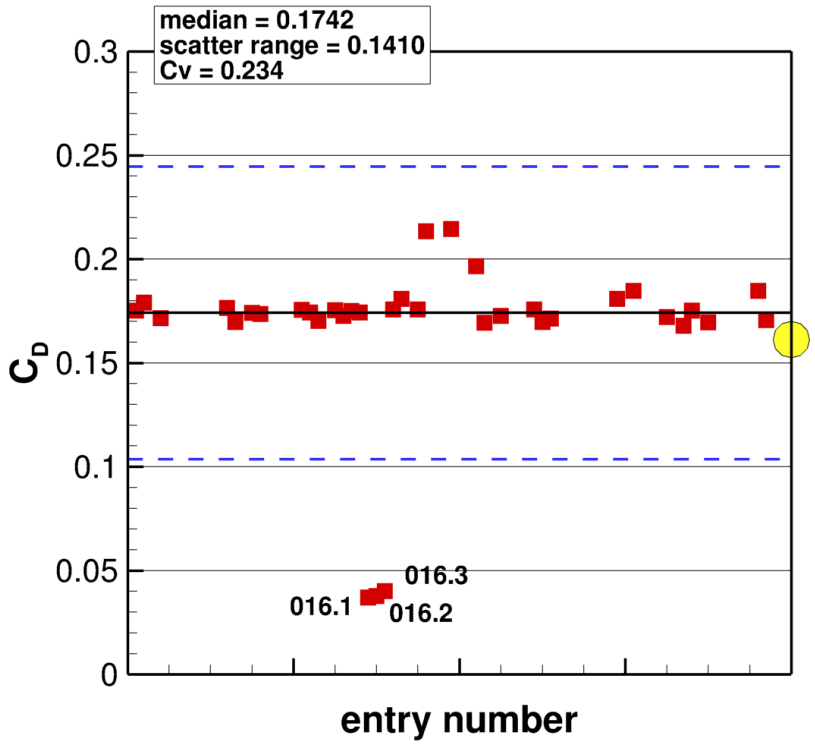


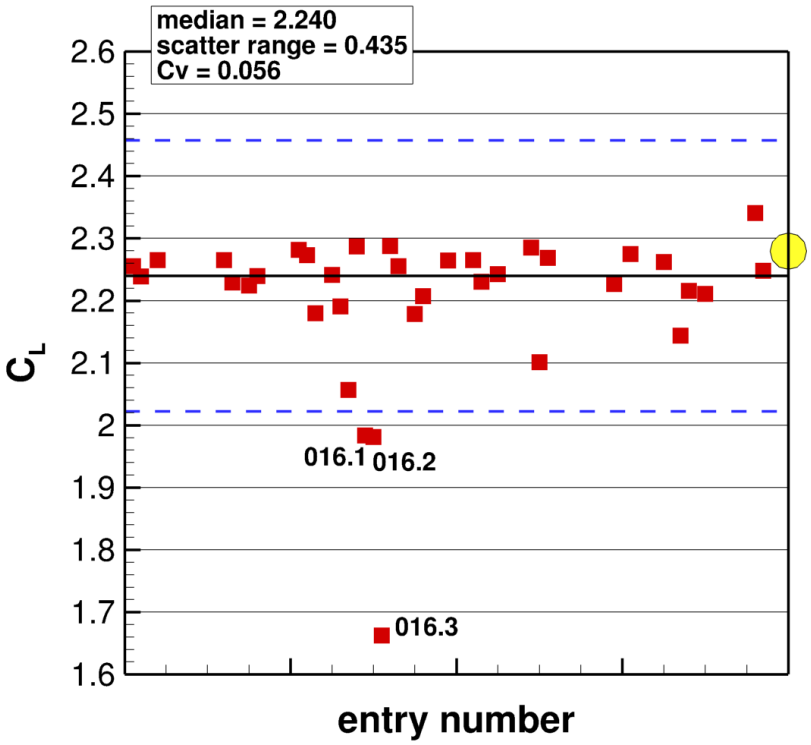

Yellow circle represents experiment

# JSM $C_L$ & $C_D$ statistics, Case 2c, alpha=10.47 deg.

CFD High Lift Prediction Workshop

With nacelle/pylon

lift

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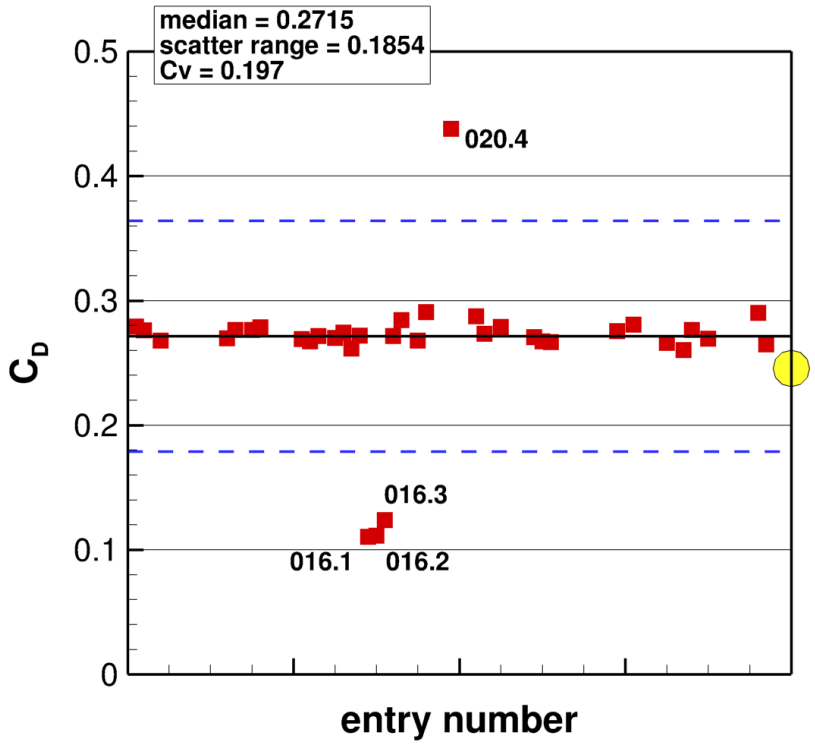


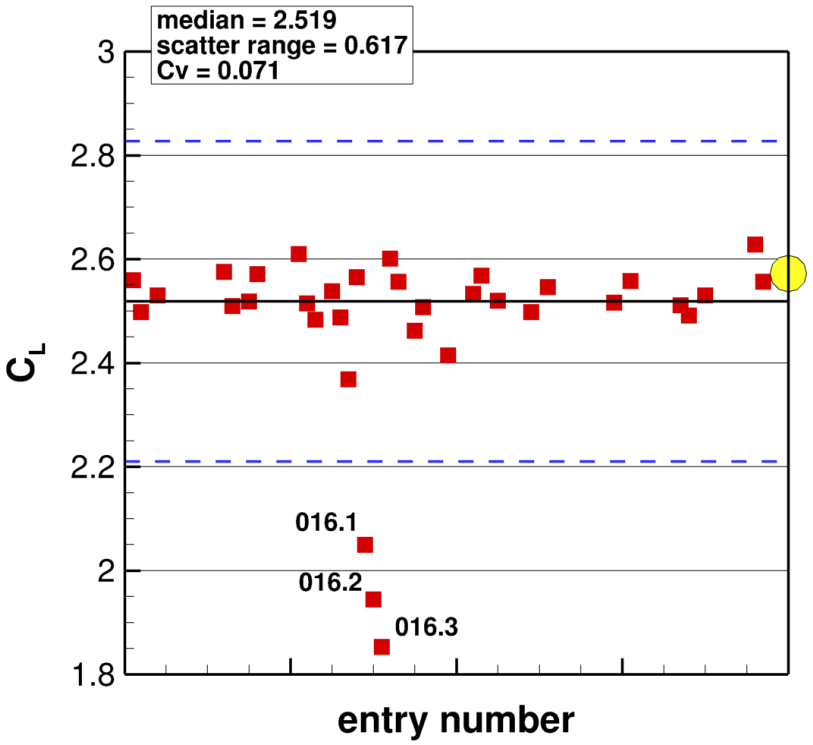

Yellow circle represents experiment

# JSM $C_L$ & $C_D$ statistics, Case 2c, alpha=14.54 deg.

CFD High Lift Prediction Workshop

With nacelle/pylon

lift

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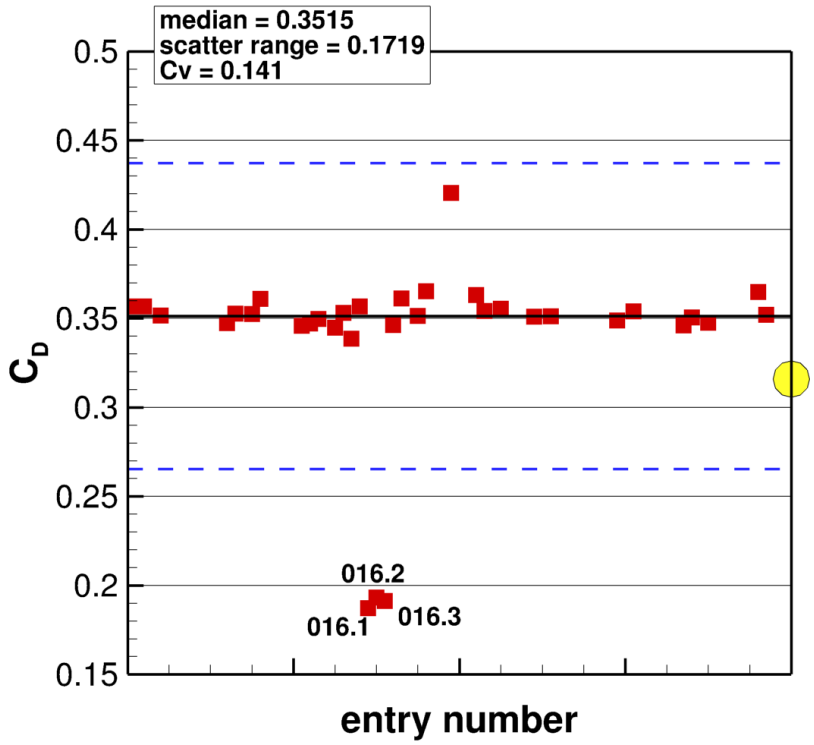


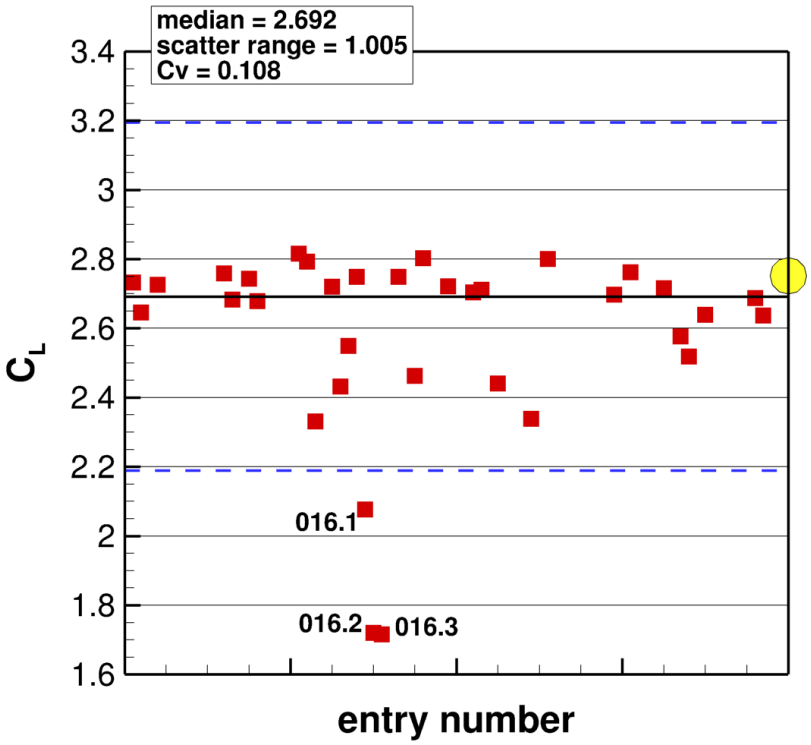

Yellow circle represents experiment

# JSM $C_L$ & $C_D$ statistics, Case 2c, alpha=18.58 deg.

CFD High Lift Prediction Workshop

With nacelle/pylon

lift

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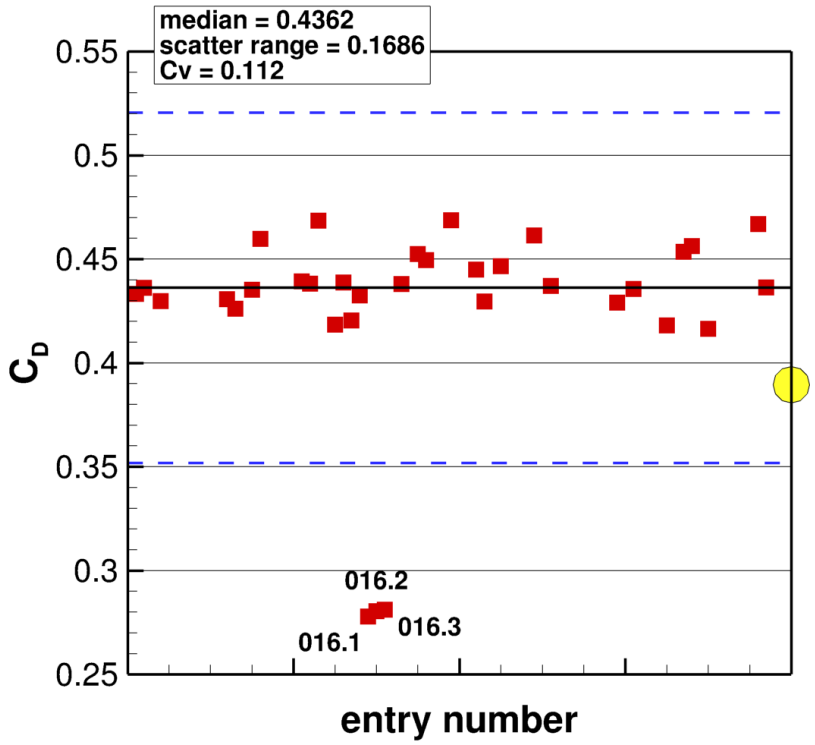


Yellow circle represents experiment

# JSM $C_L$ & $C_D$ statistics, Case 2c, alpha=20.59 deg.

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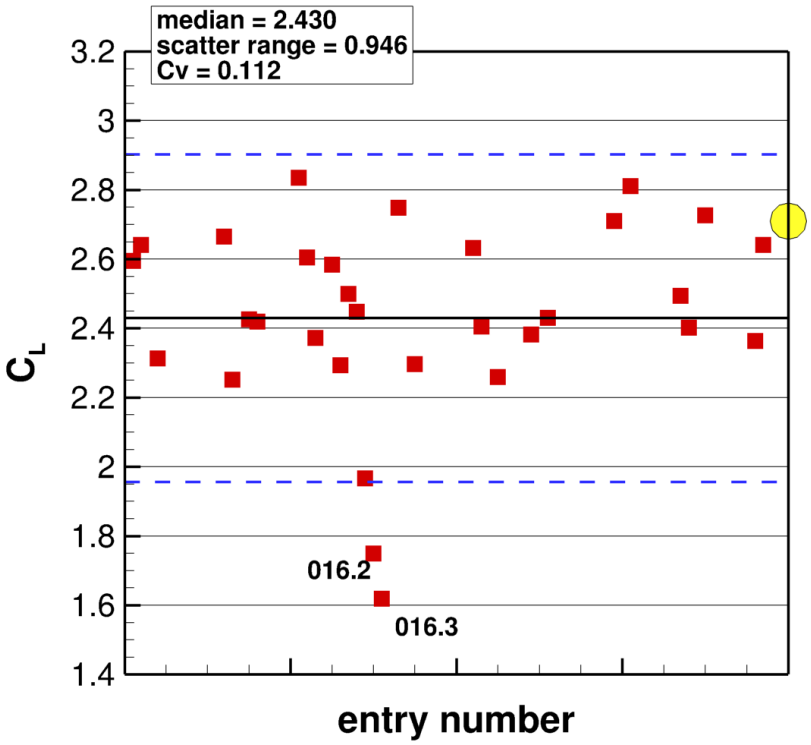
With nacelle/pylon

lift

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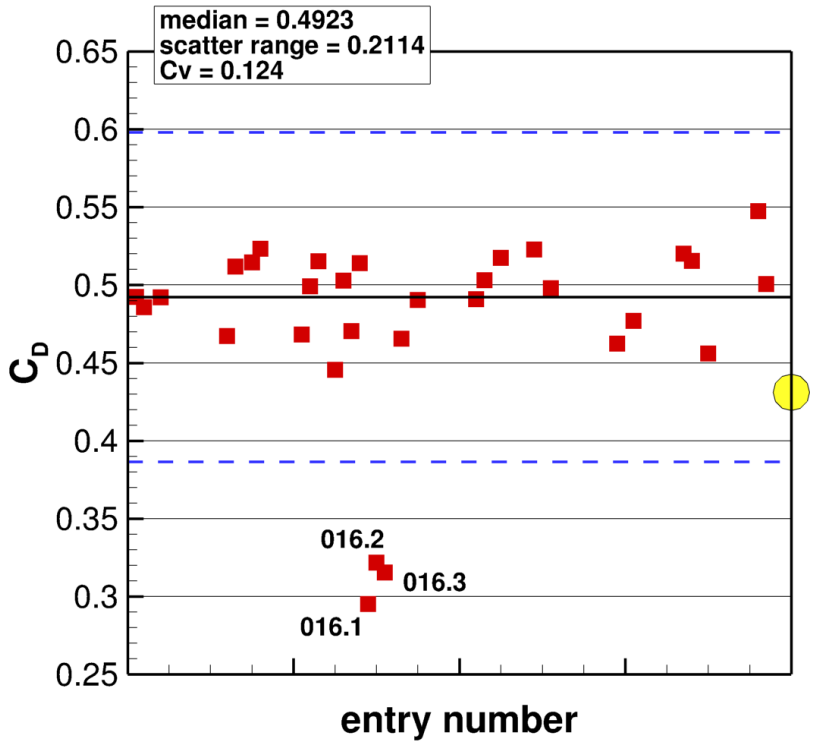


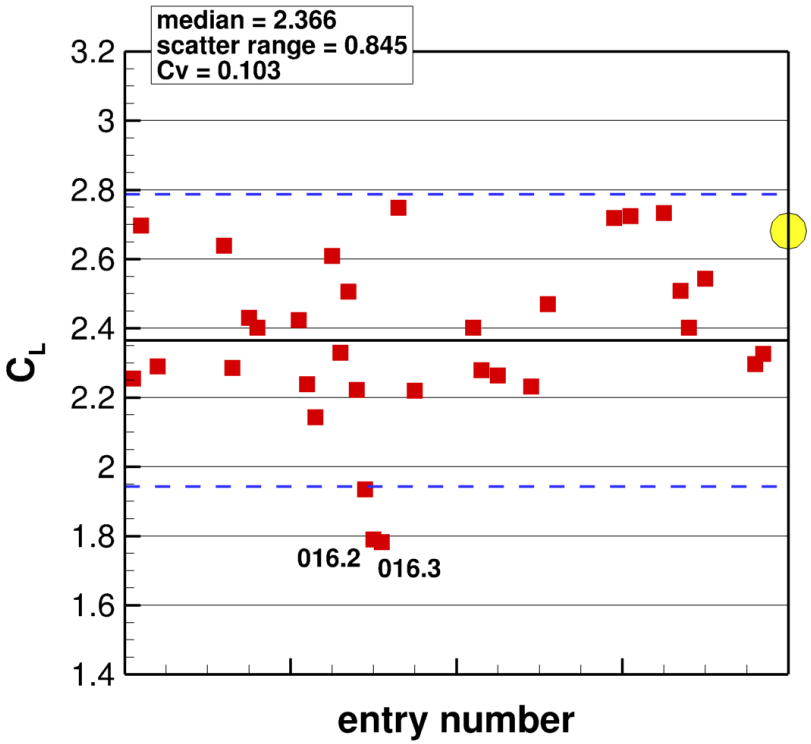

Yellow circle represents experiment

# JSM $C_L$ & $C_D$ statistics, Case 2c, alpha=21.57 deg.

CFD High Lift Prediction Workshop

With nacelle/pylon

lift

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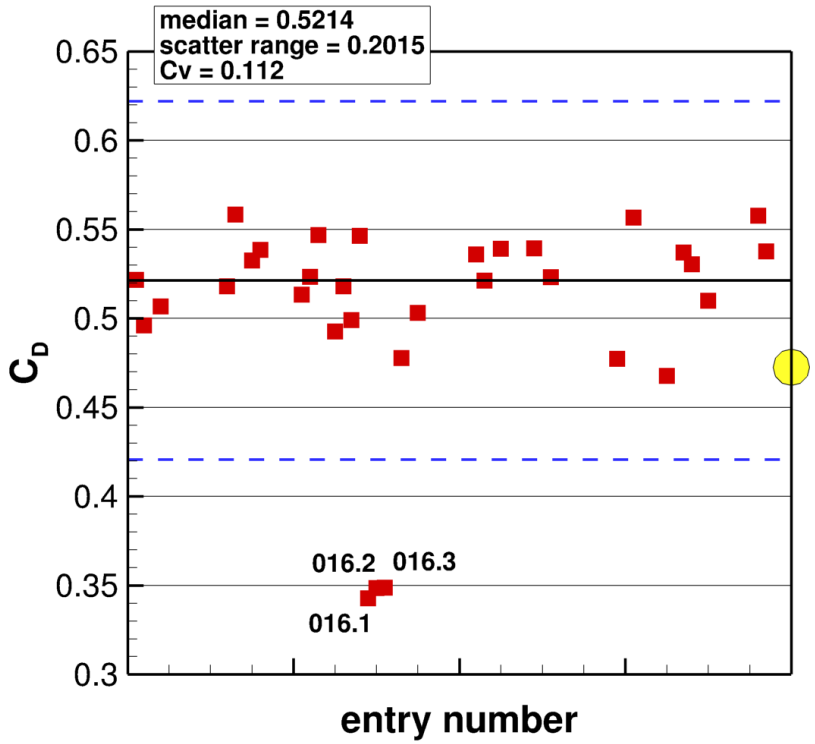


Yellow circle represents experiment